PRELIMINARY DESIGN CONSIDERATIONS FOR A SHIPBOARD DAMAGE CONTROL MONITORING SYSTEM

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THESIS

PRELIMINARY DESIGN CONSIDERATIONS
FOR A SHIPBOARD
DAMAGE CONTROL MONITORING SYSTEM

by

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At present ships are monitored for fire, flooding, and other casualties by watches such as the Sounding and Security Watch, but casualties still cause millions of dollars of damage each year. The need for a damage control monitoring system is discussed in detail and the design requirements for a system are identified. A number of alternatives for a monitoring system are examined, and one of these alternatives is recommended for implementation and prototype testing. The proposed system, which

uses a network of fire and flooding detectors in individual compartments connected via a power line carrier to a central processor, can be developed at exceptionally low risk using existing technology and at a price that can be afforded. The system would provide comprehensive damage control monitoring, and could be adapted to include equipment monitoring, record keeping, and analysis functions.

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by

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ABSTRACT

At present ships are monitored for fire, flooding, and other casualties by watches such as the Sounding and Security Watch, but casualties still cause millions of dollars of damage each year. The need for a damage control monitoring system is discussed in detail and the design requirements for a system are identified. A number of alternatives for a monitoring system are examined, and one of these alternatives is recommended for implementation and prototype testing. The proposed system, which uses a network of fire and flooding detectors in individual compartments connected via a power line carrier to a central processor, can be developed at exceptionally low risk using existing technology and at a price that can be afforded. The system would provide comprehensive damage control monitoring, and could be adapted to include equipment monitoring, record keeping, and analysis functions.

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I. INTRODUCTION

A. PURPOSE

A paper titled "A Damage Control Monitoring System," presented at EASCON-76, proposed that an inexpensive damage control monitoring system be developed to provide naval ships with a system designed to reduce the watch requirements and also reduce losses due to fires and floodings [11]. This thesis is intended to amplify on that proposal.

Sufficient information is provided in this thesis to show that a damage control system is feasible and desirable, that it can be developed with low risk using existing technology, and that its development, manufacture, installation and maintenance can be accomplished at a considerable dollar savings to the Navy.

B. BACKGROUND

1. Shipboard Casualties

To establish the severity of the fire and flooding problem on naval ships, previous reports on the subject were examined. Two reports, "Patrol Frigate Machinery Space Fire Protection and Safety Hazards Study" and "Safety Analysis of

Lube Oil Systems" used the same data and produced similar results [17,22]. These reports contain a compilation of data on 825 fires which occurred on naval ships from 1954 to 1972. The fire data in these reports were evaluated by grouping the fires according to cause factor and cost. Figure 1, a summary taken from these reports, shows a 3-dimensional histogram where the height of a block is proportional to the number of events in a particular cause and cost category.

A third report used the narratives of fires, explosions and floodings for a three year period from July 1969 through June 1973 [23]. From the narratives, the compartment in which the casualty occurred and the cost of the casualty was obtained. A hazard index for each compartment was then established by assigning a cost factor and frequency factor as explained in Table I below.

Eq.: Hazard Index = Average Cost Factor + Frequency Factor			
Accident Average Cost	Cost Factor	Frequency of Occurence	Frequency Factor
0-100	1	1-10	1
101-500	2	11-20	2
501-2,000	3	21-30	3
1,001-5,000	4	31-40	4
5,001-10,000	5	41-50	5
10,001-50,000	6	51-60	6
50,001-100,000	7	71-80	8
500,001-1,000,000	9	81-90	9
1,000,001-	10	91-100	10

Table I. - COMPUTATION OF HAZARD INDEX

A number of tables were then prepared which listed fire data, explosion data, flooding data and a combined hazard ranking. The tables were further subdivided to put ships into four groups; auxiliary ships, cruiser/destroyers, carriers, and amphibious ships. As there was considerable similarity across the four groups in the compartment names having casualties, a listing of compartments by hazard

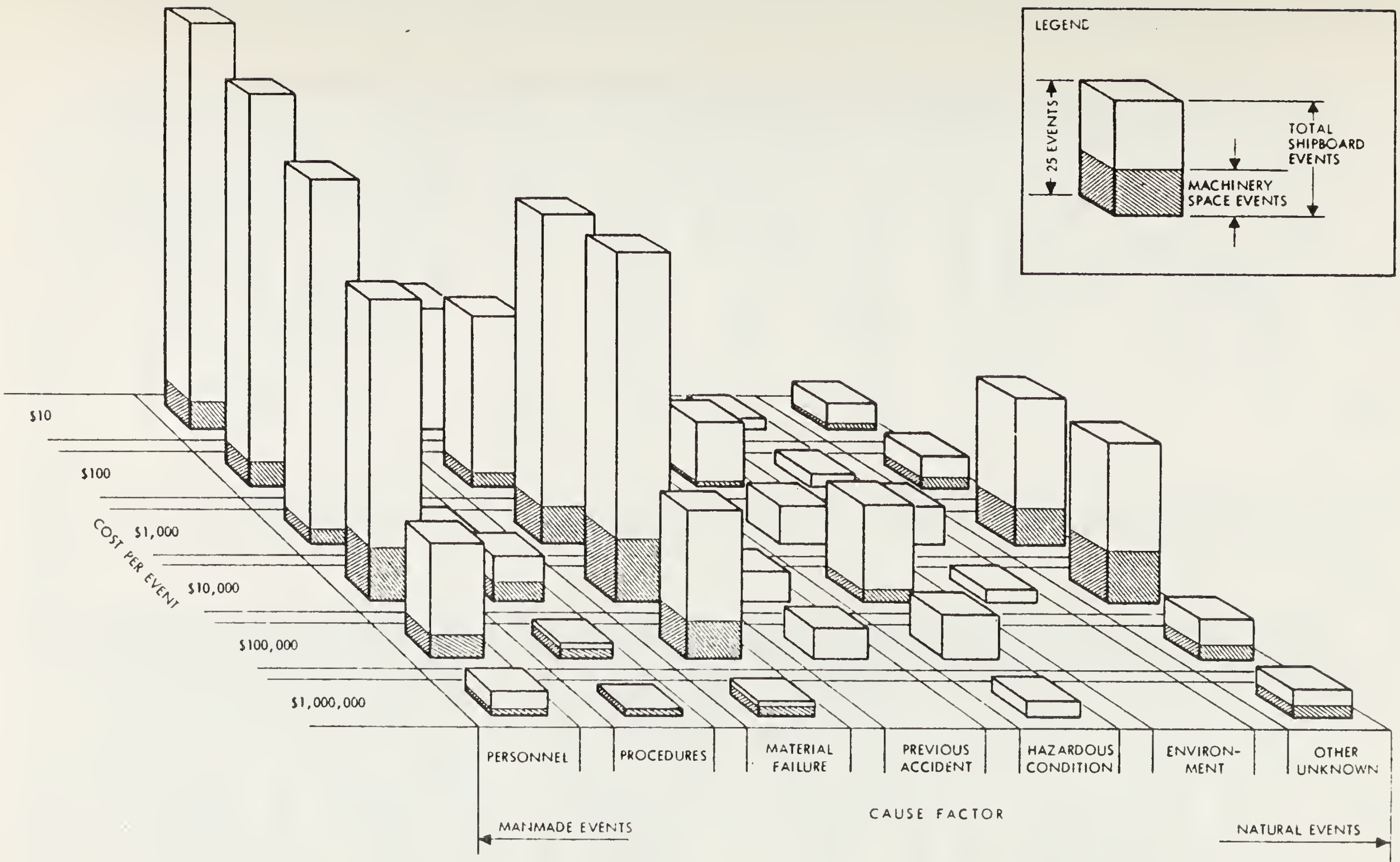


Figure 1 - FREQUENCY PROFILE OF SHIPBOARD FIRES

ranking was made from data in the report. The hazard ranking for this list, Table II, was obtained by summing the hazard ranking for each type of casualty (fire, explosion, flooding) and then summing over each ship group.

Engine Room	88	Boat Deck	8
Fire Room	68	Forecastle	8
Laundry/Dry Clean Rm.	37	Radar Control Room	8
Storeroom (Supply)	37	Cable Trunk	8
Fire Pump Room	34	JP-5 Pump Room	8
Auxiliary Mach. Room	33	Pipe Shop	8
Storeroom (General)	32	Gun Mount/Turret	8
Boiler Room	32	Flight Deck	7
Switchboard	31	Fresh Water Tank	7
Diesel Generator Rm.	31	Wardroom Pantry	7
Magazine	29	Engineers Storeroom	7
Crews Quarters	26	Hold	7
Refrigeration Mach. Rm.	26	Deck Gear Locker	7
Shaft Alley	25	Landing Force Locker	7
Motor Generator Room	23	Missile Dir. Mach. Rm.	7
Dry Provisions Strm.	22	Pilothouse	7
Galley	17	Radio (Aux.)	7
Sonar Equipment Room	17	Winch/Crane Cont. Sta.	7
Vent Outlet	16	Bow	7
Fantail	16	Gas Cylinder Stowage	7
Flag Space	16	Catapult Cont. Station	6
Air Condition Mach. Rm.	16	Chain Locker	6
Radio Transmitter Rm.	15	Elevator Trunk	5
Stack	15	Evaporator Room	5
Boatswains Locker	14	Catapult Mach. Rm.	5
Signal Bridge	14	Chill Room	5
Access Trunk	14	Arresting Gear Room	5
Steering Gear Room	14	CIC	5
Radar Trans. Equip. Rm.	14	Foundry	5
Cargo Deck	14	Crews Head	5
Hanger Deck	13	Machine Room	5
Fan Room	13	Washroom, Crews	5
Diesel Fire Pump Room	13	Chaplain's Office	5
Elevator	13	Fuel Oil Pump Room	5
Fire Control Station	13	Workshop, Machine	4
Fuel Oil Tank	13	Flamm. Liquids Strm.	4
Bilges	12	Boat (Other)	4
I. C. Room	12	Workshop, Shipfitter	4
Passageway	11	CPO Mess	4
Elevator Machinery Room	11	Void	4
Boat (Whale)	11	Refueling Station	4
Lounge	11	Oxygen Storage	4
Amplidyne Room	11	Barber Shop	3
Compressor Room	11	Damage Control Locker	3
Incinerator	10	Life Jacket Locker	3
Office (Dept/Div)	10	Washroom, Officers	3
Workshop, Electrician	10	Air Vent Inlet	3
JP-5 Tank	10	Medical Space	3
Officers Quarters	10	CPO Quarters	2
Storeroom (Medical)	10	Crews Mess	2
Wardroom	10	Ordnance Space	2
Aviation Ordnance Shop	10	ECM Mast	2
Chemical Warfare Locker	10	Ship Control, Secondary	2
Tank Deck	10	Workshop, Electronic	2
Anchor Windless Room	9	Aircraft Fueling Station	2
Radio Central	9	Captain's Cabin	2
Ballast Pump Room	9	Capstan Machinery Room	2
Drying Room, Aviation	9	Communications Center	2
Laboratory	9	Main Control	2
Uptake Space	8	Damage Control Shop	2

Table II. - COMBINED HAZARD RANKING BY COMPARTMENT NAME

Figure 1 serves to show the causes of fires and Table II lists the most hazardous compartments but neither answers the basic question of whether or not a damage control monitoring system would have an impact on the severity of the casualties. To answer this question narrative reports of all reported fires having damage assesments in excess of $10,000 and floodings in excess of $1,000, were obtained from the Naval Safety Center, Norfolk, Virginia [16]. The narratives were then put into three groups; (1) casualties where a monitoring system would have prevented losses, (2) casualties where a system might have reduced the losses, and (3) casualties on which a monitoring system would have had no effect.

The narratives in the first and second group revealed that many of the fires have two things in common. First, they begin slowly, sometimes smoldering for hours in a closed compartment before being discovered. Second, when discovered the smoke is so thick that fire fighters are unable to locate the source of the fire for many minutes. The nature of shipboard construction designed to prevent the advance of fire and flooding effectively prevents the discovery of the casualties as well.

Many of the costly fires, falling into group three, were oil fires which began in engineering spaces as a result of oil igniting when in contact with operating machinery. No monitoring system, unless coupled with some form of automatic extinguishing system, will reduce the effects of these fires. The purpose of those studies mentioned above was to locate the causes and hazards so that such automatic detection and extinguishing systems could be designed for future ships. As it is unlikely that the future systems designed will be back fitted to existing ships, there is a program to isolate the sources of oil and to insulate all

machinery which operates above the ignition temperature of the oil. This program has reduced somewhat the frequency of oil fires.

Two attempts were made to correlate the results determined from the 1973-1975 data with that from the 1954-1972 period. During the earlier period, 39% of the total fires had damage in excess of $10,000, while it was 15% for the later period. The most probable reason for the difference is in the method of gathering the data.

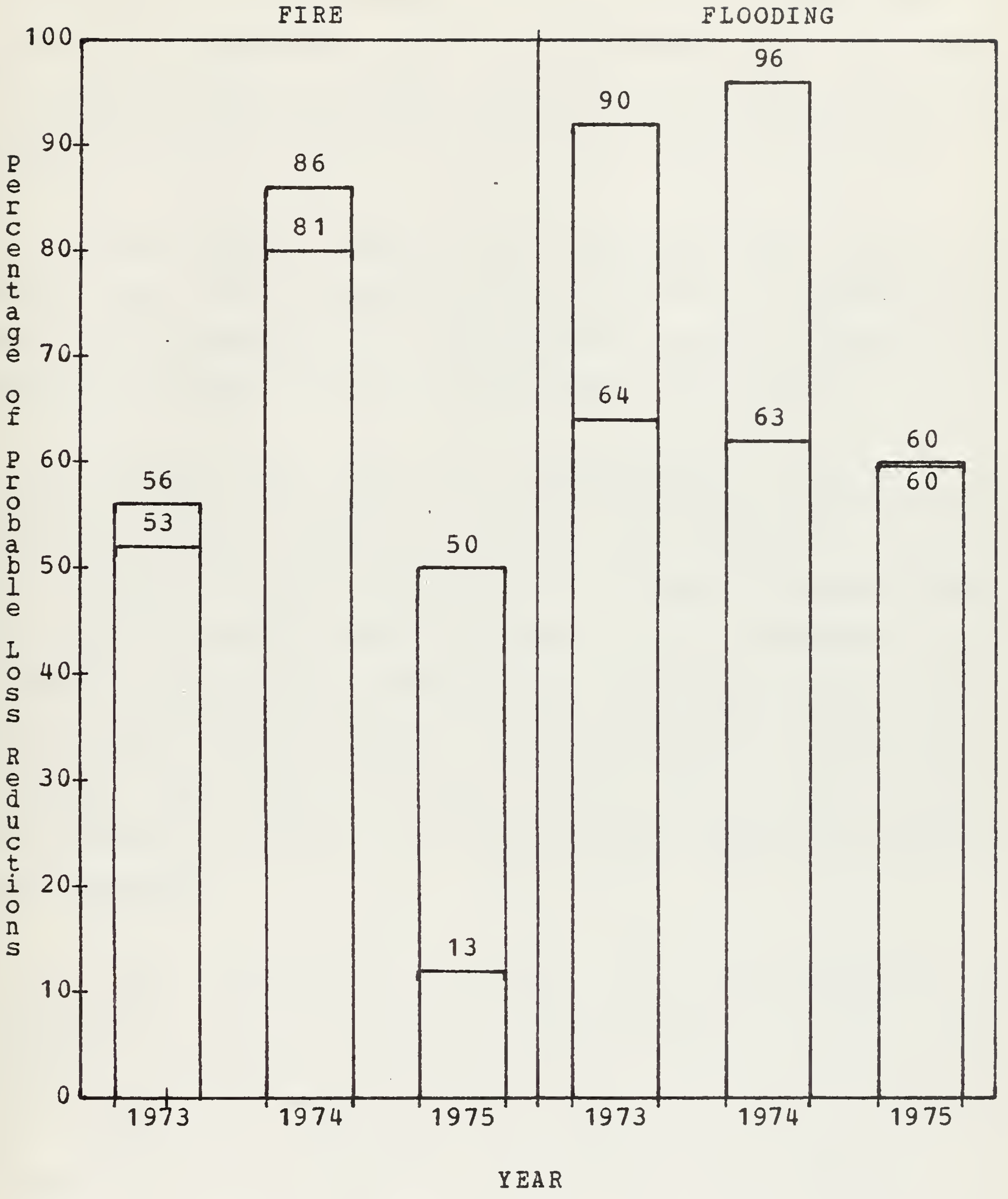
Prior to 1970, the Naval Safety Center served primarily as a repository for reports. In the early 70's, the Safety Center began to put its information on computer files and to cull supply requisition records and other sources for data on all types of casualties. As a result the number of casualties recorded on the data files has significantly increased. These increases have been primarily the low cost casualties which were not previously reported to the Safety Center for one reason or another.

Because of the likelihood that during both periods the most costly fires had been reported, a second attempt was made to correlate the percentage of fires in the $10,000 and above range with the percentage of total losses. It was found that during the 1973-1975 period, 15% of the fires produced 96% of the damage and during the 1954-1972 period, 13% of the fires produced 92% of the losses. It can be seen then that analyzing additional reports on numerous small fires (less than $10,000) would not impact the results. It is therefore felt the results obtained from a small sample of the most costly fires was a good indicator of the material losses that could be reduced with a damage control monitoring system.

Based on the narrative report analysis, the graph in Figure 2 shows the percentage total losses due to both fire and floodings which could have been saved had adequate monitoring been available in the years 1973-1975. The lower percentage (Group 1 casualties) represents the total losses which a monitoring system would have prevented by alerting personnel of the casualty. The higher percentage (Group 1 plus Group 2 casualties) represents losses which probably would have been considerably reduced had a monitoring system been available to reduce the time between the initiation of a casualty and the steps taken to correct the casualty. On the average over the three year period, 48% and 61%, respectively, of the fire and flooding losses could have been eliminated. An additional 13% and 9% of the total losses might have been reduced by a monitoring system.

2. Damage Control Monitoring

The traditional method of detection and monitoring aboard naval ships is the sounding and security watch, the below-decks watch, cold-iron watch or roving patrol. All naval ships maintain one or more of these watches 24 hours a day. The principal watch is the sounding and security watch. The man on watch periodically makes rounds of various spaces checking for fire and flooding, monitoring material conditions, and providing security. The man is also required to maintain an extensive record of equipment status and operating parameters. As a result, the watch, in the normal execution of his duties, may not visit portions of the ship any oftener than every one to two hours. In addition to its infrequency, this method of monitoring has a number of other inherent drawbacks. For instance, the man on watch does not have access to locked offices and storerooms. He can not, without the aid of instruments,



TOTAL VALUE REPRESENTED: $30,000,000

Figure 2 - SAVINGS USING DAMAGE CONTROL MONITORING

detect toxic gases, carbon dioxide, carbon monoxide, and temperatures or pressures with any degree of accuracy. At worst, an individual may be ineffective in his duties through physical illness, exhaustion, boredom, inattention to detail, lack of adequate training or any combination of these.

The cost of repairs, lost training time, lost man hours and the occasional loss of life due to casualties is all out of proportion to the immediate damage suffered. Two instances should suffice to illustrate this effect.

Aboard one ship a conscientious sounding and security patrol attempted to pump a storeroom bilge. He lit off the eductor, checked for proper operation and continued his rounds. Shortly thereafter the eductor became clogged and back flooded the storeroom. Upon returning, the sounding and security patrol found the water to be 6-8 feet deep. The eductor was secured, the storeroom dewatered and the cause of the accident was discovered to be the clogged eductor. The immediate effect on the ship and its mission was minimal. However, the following was required to restore the casualty:

An immediate inventory of the storeroom was conducted. The storeroom contained electronic spares which began to corrode upon reexposure to the air after the salt water bath. The majority of the spare parts were discarded as unusable or unreliable and replacements ordered. Two weeks of continuous work was required for the inventory and reordering, and six months later, not all of the parts had been received. An electric motor and pump in the compartment also were covered with water. The motor required removal from the ship, cleaning, baking, testing aboard a tender and return, all of which required three weeks of routine work.

After drying of the insulation on the storeroom bulkheads, a thorough cleaning to prevent further corrosion was required and the storeroom repainted. An investigation was conducted and a report generated requiring additional manhours in questioning witnesses, and compiling the report. Material damage reported to the Naval Safety Center--$0, no operating equipment was destroyed, no lives were lost, and no outside contract was required to effect repairs.

Aboard the same ship some time later a fire started in a closed pumproom apparently from a carelessly discarded cigarette. The fire smoldered for some time, filling the pumproom with dense black smoke. Again the sounding and security watch discovered the fire. It was difficult to put out because the pump room is inaccessible and it was difficult to get equipment to the scene through the smoke while wearing oxygen breathing apparatus. As it turned out the fire had caused very little damage, only burning a few rags and some gasket material that had caused the dense smoke. Smoke damage in the vicinity of the fire was heavy and required that personnel's clothes and bedding be washed. Bulkheads and overheads of nearby compartments also required washing to remove soot and smoky odors. An investigation and report was also required here. The fire fighting water used to extinguish the fire had gotten on the pumps in the pumproom and required extensive cleanup before an attempt was made to use them. Material damage reported to the Naval Safety Center--$0.

The important fact about both these shipboard casualties and many others is that, even with conscientious sounding and security watches, they resulted in extensive losses. If these two casualties had been detected earlier it is likely that no damage would have resulted and the report to the Naval Safety Center could have correctly reflected the situation, two casualties, damage zero.

The need for continuous monitoring is well established and watches are maintained aboard Navy ships from before initial commissioning in a building yard until final decommissioning many years later. Manpower cost estimation for the sounding and security watch based on "Navy Military Manpower Billet Cost for Life Cycle Planning Purposes," NAVPERS 15163, is $13,600 per man-year. The Sounding and Security Watch requires three men to man a 24 hour Condition III (Peace Time) watch. The cost per year then is $40,800. The life cycle estimate of 20 years for a ship would place the manpower cost of the sounding and security watch at $816,000. This is a great deal of money to spend to maintain a system which has proven to be totally inadequate.

In a report, "Replacement of Roving Patrol Sounding and Security Watch with Automation Based on T-AGOR 16 Installations," it was concluded that on the Patrol Frigate it would cost $215,924 to purchase, install and maintain a monitoring system to do the job of the sounding and security watch [35]. The sounding and security life cycle cost had been estimated at $600,000, resulting in a life cycle savings of $384,076. This report demonstrates that the life cycle cost of continuous manpower exceeds the life cycle cost of a monitoring system by a significant amount. Were any monitoring system able to demonstrate high reliability and low false alarm rates, it could replace the sounding and security watch.

The fire and flooding detection systems available on most ships today consists of one or more temperature thermostats in the ammunition magazines, temperature thermostats and smoke detectors in missile magazines, if the ship has them, and float switches to indicate high water levels in the fire rooms, engine rooms and auxiliary machinery rooms. Each magazine or compartment monitored has

an individual circuit wired to an alarm panel usually located in Damage Control Central. The system is energized at all times and will sound an alarm at two or more normally manned locations. Appendix B contains a list and description of the monitoring and alarm systems installed in the Coontz class destroyer.[1] These systems are typical of most installed monitoring systems in the fleet today. These systems are rugged, extremely reliable, and require little maintenance. However, the systems are very limited and the few expansions of the systems attempted have been exceedingly expensive. Therefore, except to expand some flooding systems to include the main engineering spaces, no plans exist for extending the monitoring system on ships now in operation. In spite of the costs, these systems have been sufficiently successful in reducing casualties that new ships are being built with a similar system throughout the ship.

The system being installed on new ships consists of two heat and smoke detectors per compartment or one for each 250 square feet of deck area and sensors to indicate high water in most engineering spaces. These detectors are wired directly from the compartment to an alarm box at a central location. During initial construction the cost of additional wiring and work required to install this monitoring system is considerably less than the cost to add wiring to a ship after construction has been completed.

The ships now in operation still have an expected useful life of from 5-30 years and without adequate monitoring the fire and flooding losses can be expected to continue. Appendix A lists naval ship classes, their

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[1] A Coontz class DDG has been selected as a basis for discussion because of the author's familiarity with this class and the fact that it represents an average size ship. Appendix B contains information and tables applicable to this ship class which will be referred to in the text.

numbers, and approximate age. This list has been included for a number of reasons. It gives an indication of the types and variety of ships a damage control system must protect. The age of each class is shown to indicate which classes could not be economically equipped with a monitoring system. One additional factor which would have a bearing on whether a damage control system would be cost effective on any class of ship is whether the particular class or type of ship has had a high or low incidence rate of fire and floodings. For instance, submarines represent 22% of the total number of ships yet report only 1.1% of the flooding incidents which amounts to 0.15% of total ship losses. For fire they report 3.8% of the incidents representing 2.1% of the total losses. Therefore, it would be uneconomical to install further damage control monitoring systems on submarines.

There are a total of 420 naval and military sea lift command ships with a life expectancy of greater than ten years. This assumes that each ship will be used thirty years. Of the 420 ship total, 115 of them are submarines leaving a potential requirement for 305 damage control monitoring systems.

II. MONITORING SYSTEM DESIGN CONSIDERATIONS

A. SCOPE OF THE MONITORING SYSTEM DESIGN

It is within the capability of present equipment to detect fire by monitoring for high temperatures and smoke, and to detect flooding by monitoring fluid levels or pressure. Furthermore, the system could monitor the status of equipment and systems. First, a system to detect flooding is needed. This requires a fluid level indicator in each compartment located below the water line and in certain other compartments which have a fire main connection, sea water cooling system, or other fluid system which could lead to flooding. For the Coontz class destroyer (see Appendix B) there are a total of 283 compartments, tanks and voids meeting the above criteria.

Fire detection on a Coontz class destroyer poses an even bigger problem as no area of the ship is immune to fire even though some compartments are more susceptible and hazardous than others. Complete coverage should be the goal for fire detection. This would require 347 detectors excluding tanks and voids. Equipment monitoring could require an additional 300 detectors. The total then would be approximately 1000 detectors of various types distributed throughout the ship.

There are various options for operation of the detectors. The detectors could be sufficiently sophisticated that they would individually monitor and sound an alarm, or they could be unsophisticated sensors which

would relay conditions to a central location where the decision to sound an alarm could be made.

The first approach assumes that someone will be close enough to hear, see and react to an alarm, and is therefore not much better than what is presently done. The second approach would seem to have an advantage in that the sensors used in such large proliferation could be inexpensive, while the central location contained the more sophisticated equipment capable of coping with any number of remote sensors.

B. THE CENTRAL LOCATION

All ships maintain one or more places where there is someone on watch at all times. In most ships Damage Control Central (DCC) is one of these places; so this is the logical control point or central location for a monitoring system. If it is assumed that detectors are available and a means to communicate from them to a central location has been established, a method must be found to process the detector intelligence for human consumption. The following devices could be adapted for this purpose:

1. An indicator panel consisting of lights and alarms would indicate the status of each detector. The technology to build such a panel is presently available, and relatively inexpensive. However any changes to the system would require rewiring the panel, perhaps re-mounting and re-labeling indicators and various other expensive operations. Further the panels would need to be individually designed for each class of ship.

2. A more mechanized device than above, where, through

relays or switches, each detector could be interrogated and an output generated on conditions out of tolerance. Again this is technologically feasible, but lacks flexibility.

3. A third approach is to use one of the recent generation of microprocessors or microcomputers. The microcomputer has proven itself capable of monitoring large numbers of points or detectors and costs have become comparable with most hardware monitoring methods.

The choice of a computer for the central processor has a number of advantages:

a. It is relatively inexpensive.

b. It has capability for rapid data acquisition, processing and dissemination.

c. The frequency of monitoring and the parameters constituting abnormal conditions can be easily changed.

d. It is light, requires little power and space and therefore is easily installed.

e. It is flexible in that changes in software would adapt the computer to various sizes and types of ship.

f. Its capabilities may be increased by adding more memory capacity.

g. The computer output can be made compatible with other information systems currently in development [8,14,24].

The addition of memory to the microcomputer could allow for a number of additional options such as equipment monitoring, analysis of the effect of flooding on ship stability, and equipment vibration analysis. At the present time the Naval Electronics Laboratory Center, San Diego, California, is working on standardizing a microcomputer and peripheral equipments that meet naval requirements [28].

C. DETECTORS

Detectors and sensors have been manufactured and used for almost every physical parameter known. The difficulty here is to select sensors which can meet the demanding environment in which they are expected to perform. In general, reliability, ruggedness, and long life have a premium over accuracy and sensitivity. Measurement for water levels, smoke detection, and temperatures may be quite inaccurate and yet suffice. More sophisticated measurements such as voltages and vibrations require both more accuracy and sensitivity.

The Naval Ship Engineering Center, Philadelphia Division, is currently working on a project intended to select and develop fire detection equipment which will provide suitable alarms in machinery spaces, magazines and living spaces and, in some cases, actuate automatic fire extinguishing systems in time to prevent major damage [21].

The approach being used is to study detector and other applicable fire literature, determine environmental variables affecting detector performance and to measure these variables aboard ship. Numerous detectors have been procured for tests. Testing will consist of small scale laboratory detector response tests and large scale burn tests to evaluate detector performance. The large scale Burn Test Site is a fully equipped Coontz class training fireroom acquired from the Naval Boilerman School.

This project is further intended to develop Military Specifications for detectors including laboratory performance tests, and to qualify detectors for shipboard use.

The Naval Research Laboratory, Washington, D.C., has a program to develop logic circuits to be used in conjunction with commercially available fire detectors to eliminate false alarms and provide a more sophisticated level of alarm [15]. The concepts which are incorporated into the logic are a sampling of ambient conditions at certain intervals, performance of signal averaging and ability to compare between averaged intervals. The comparison can be used to determine a rate of rise or fall and the magnitude and duration. The logic has four output levels corresponding to four levels of alarm. The first is Standby, the second is Check, the third is Alert, and the fourth is Full Alarm. The logic has been breadboarded and tested with simulated analog data.

The July 1976 issue of Control Engineering has an article on various types of level sensors all of which are sufficiently rugged to be candidates for a shipboard system [2].

D. TRANSMISSION

A number of methods are available for transmission of the detector data to the central processor. Among the possibilities are radio telemetry techniques, sound transmission, laser or optical fiber devices and two wire transmission lines.

Radio telemetry, while reducing the requirement to install wiring, etc., would be difficult to maintain and would interfere with existing communication equipment. Sound transmission is impractical for a number of reasons such as high ambient noise and compartmentalization which would necessitate numerous retransmissions.

Laser and fiber optics technology promises to provide a viable transmission method for a monitoring system aboard ship [30]. A number of projects are currently underway to test and evaluate fiber optics aboard ships and aircraft. The preliminary results have been very successful and future monitoring systems will very likely use this technology. There are two reasons, however, that would rule out fiber optics for this proposed system. First, the expense of back-fitting a system requiring access to every compartment on a ship is prohibitive, and prevents the installation of present systems on older ships. Second, if installation were to take place, there is little need to install a transmission device with the broad band capabilities of fiber optics when a simple two wire system would suffice.

As previously stated, the cost of installing two wire transmission lines is prohibitive. However, transmitting information (data) signals over existing cabling has some possibilities. For example, LCDR D. E. Bienlien in a thesis "A Frequency-Division Multiplex System for Use in Shipboard Internal Voice Communications," describes the building and testing of a voice communication system utilizing the bandwidth between fifty and two hundred kilohertz [3]. The system used the existing sound-powered telephone lines. The sound-powered telephone system aboard ship, though quite extensive, still does not reach all areas where damage control monitoring would be desirable. It was also found that the sound powered head sets would require modification because non-linearities in the electrical response of the head sets demodulated the data on the carrier frequency.

The only cabling presently installed that reaches nearly every compartment aboard ship is the 60Hz lighting and power distribution system. Power line carrier systems have been used extensively in Europe to control loads, monitor switching, and maintain internal communications within the

power distribution system. This method has been used successfully for commercially produced intercoms [29] and remote audio speaker [31] installations. Power line carrier systems in use by power companies have carrier frequencies up to 500 kHz thus allowing for a number of simultaneous channels [26,32]. The short distances involved and therefore the signal power needed aboard ship would minimize the effect of radio frequency interference.

The Naval Ship Engineering Command, Hyattsville, Maryland, was asked to comment on the use of a power line carrier alarm system [19,20]. Their reply was to caution that the addition of an RF signal in the lighting circuit wiring is undesirable since the signal will be radiated within the shipboard environment, potentially causing interference to electronic systems. They however suggested the following considerations be applied in the design of such a system:

1. Signals radiated into electronic equipment spaces or conducted on power lines to electronic equipment by the alarm system should not exceed the MIL-STD-461 requirements for equipment susceptibility.

2. A carrier frequency between 30 kHz and 100 kHz should be used, avoiding common Navy users in this range such as Loran "C" at 100 kHz. Harmonic content of the telemetry signal should not exceed 2 MHz to preclude interference with HF receiving systems. The 30 kHz to 100 kHz frequency range is recommended because (1) signals in this range can be transmitted along lighting circuits with minimal attenuation, (2) minimal E and H field radiation occurs at these frequencies from shipboard wiring, and (3) this part of the electromagnetic spectrum is relatively free from heavy use.

3. The telemetry signal level should be as low as possible (1 volt or less is suggested).

E. ALARMS

Regardless of the type or manufacture of any sensor for the monitoring system, the sensitivity to each parameter must be measured, and the conditions which would require an alarm must be determined.

1. Flooding

Consider first the flooding situation, and look at the conditions under which the sensor must operate. Some compartments aboard ship, such as storerooms, magazines, and voids, should essentially remain dry and any amount of water or other fluids would constitute an alarm condition. Engineering compartments, on the other hand, contain some water at all times as the result of the constant water leakage used to cool pump packings and the routine small leaks at fittings and valves. These compartments usually contain bilge pockets to collect this water. The bilge pockets are then periodically pumped to holding tanks or to sea. Often, however, when both the holding tanks and bilge pockets are full, the water is allowed to continue its rise because the Environmental Pollution Control Act prohibits the discharge to sea of wastes in ports, rivers and along the seacoast. In most cases the increased water level does not constitute a hazardous condition until it has reached a level several feet above the bilge pockets and approaches the level of pumps, motors and other equipment that could be damaged. Therefore there are two normal situations which constitute an alarm condition, when the bilge pocket is full, and when the level approaches equipment. Neither of these alarm conditions would constitute an emergency situation.

There is also the situation of catastropic flooding such as when a pipe breaks or a valve is inadvertently left open. In this situation a substantial increase in water level in a short period of time constitutes an emergency alarm.

Assuming that a central processor at a remote site will be making the decisions, a sensor must provide sufficient data for the decision to be made. Obviously the easiest method would be to install a simple ON-OFF switch at the highest point the level should be allowed to reach. In the case of a normally dry compartment the switch would be installed as low as possible. In wet compartments the switch should be installed at higher levels. It can be assumed that normally dry compartments have emergency flooding conditions when the switch comes "ON". In a wet compartment this is not true and an "ON" condition may mean only that routine pumping is required. In wet compartments then, additional ON-OFF switches would be needed for the emergency situation. The number of switches needed and the requirement to maintain and test them appears to require that other methods be investigated.

A continuous or incremental sensor would seem to be the answer in both wet and dry compartments. It would indicate the fluid level from zero to any desired level. The rate of rise could be determined by the central processor and an alarm could be sounded as necessary. A further advantage is that only one kind of sensor would be needed.

The next determination is the sensitivity of the fluid level sensor. This depends on the additional uses of water level information. For instance, if the system is intended to be capable of determining ship stability then the sensor must be able to indicate a substantial number of

levels between empty and full. If the system is limited to monitoring the level above which an emergency exists then a relatively few levels would suffice. There then must be a trade off between the complexity of the sensor and the number of levels the sensor can indicate.

As with any system the sensor information must be converted to an electrical signal. This signal may be a variable frequency, current, or voltage. Voltages between 0-10 volts or ±5 volts are most commonly used and any frequency or current can be converted to a voltage in this range. Most level sensors on the market provide a voltage output.

2. Fire

There are four stages in a fire's development [13]. The early or incipient stage is characterized by the thermal decomposition of combustible materials. The gases and particles produced at this stage are invisible. The second or smoldering stage produces larger particles visible as smoke. The third or flame stage results in heat igniting gases and particles. The heat ignition of gases and particles is followed quickly by the final high heat stage which results in rapidly expanding flames.

Detection of fire is dependent on recognizing a fire's signature [12,18]. In the two initial stages of a fire, detection depends for the most part on sensing the presense of aerosols, the small particles of combustion which, when large enough, appear as smoke. To a lesser extent the gas signature, oxygen depletion and an increase in carbon monoxide and carbon dioxide, may be used to indicate the presence of fire. In the later stages of a fire, detection merely depends on sensing the vast amount of

energy released in the form of radiation. Infrared, visible, and ultraviolet radiation can be detected directly or may be detected by an increase in temperature.

The environmental conditions for heat sensing are similar to those for flooding in that some compartments are normally at a comfortable living temperature while engineering spaces normally operate at somewhat higher temperatures. Here again an emergency alarm condition may be dependent on either a temperature above a certain level (different for each compartment) or on a sudden increase in temperature.

As with flooding detectors, the heat sensor could be a simple ON-OFF device set to a given temperature but this method would require that the set point either be high enough for any compartment or set differently for each compartment. A single set point has the disadvantage that compartments with low ambient temperatures would have to have a considerable amount of heat introduced to reach the alarm condition. This would require that a fire be well underway prior to the alarm being sounded. The object of the system is to discover the fire and alert personnel to put the fire out before the fire becomes uncontrollable. Individual compartment set points would require an involved procedure to determine set points and check the proper alarm temperature. The temperature sensor must be able to indicate a quantative value in terms of a voltage in the 0-10 volt range.

III. STATE-OF-THE-ART IN DATA-ACQUISITION SYSTEMS

A. WHAT IS DATA ACQUISITION?

In the terminology used today, data acquisition is the process which interfaces a control unit to the "real" analog world [4,33]. In a damage control application, the real world of interest consists of parameters such as fluid level, temperature, smoke level, etc. Most data acquisition systems (DAS) now on the market cost several thousands of dollars. The cost depends primarily on the number of inputs and the speed at which the DAS can process the inputs.

A typical DAS in use today might be a large rack-mounted device weighing 50 pounds or more, consuming over 100 watts of power and having 256 input channels. It is generally hard wired to the sensors and requires pre-amplification or other costly signal conditioning in order to obtain the accuracy and immunity to external electrical noise required for remote sensors.

All data acquisition systems usually contain the same component nucleus. A typical system would consist of an analog multiplexer, an instrumentation buffer amplifier, one or more sample-and-hold amplifiers, a high speed analog-to-digital converter, and a logic control section which controls the input selection and timing for the entire data acquisition process. The system is designed to take a set of analog inputs and convert them to digital values for use by a process controller or computer.

B. MAKING THE DATA ACQUISITION SYSTEM SMALLER

With the advances in microcircuit techniques over the past few years it is now possible to obtain a complete data acquisition system on a single printed circuit board for several hundred dollars. These DAS's contain the same component nucleus as the older and larger systems but use integrated circuits as building blocks for the system.

The trend toward smaller and less expensive data acquisition systems can be expected to continue. A number of companies have produced products within the last year that can be integrated into an inexpensive system. For instance, Analog Devices, Inc., has a sample-and-hold amplifier that sells for $5.95 where the range had previously been from $25-$253. Teledyne Semiconductor has an eight-bit analog-digital converter for $9.95 compared to previous components ranging from $19-$195.

Micro Networks Corporation through the application of thin-film hybrid technology has produced a complete eight channel data acquisition system in a single 32-pin dual-in-line package (DIP) [5]. The device, MN7100, sells for $140 each in 100-unit lots. Data Translation, Inc., has a low cost data acquisition module, DT820, selling for $130 in quantities of 100 [7]. This unit also contains eight channels in a 32-pin DIP. It can be expected that other companies will shortly produce similar DAS's at competitive prices. A block diagram of the Micro Networks device is shown in Fig 3.

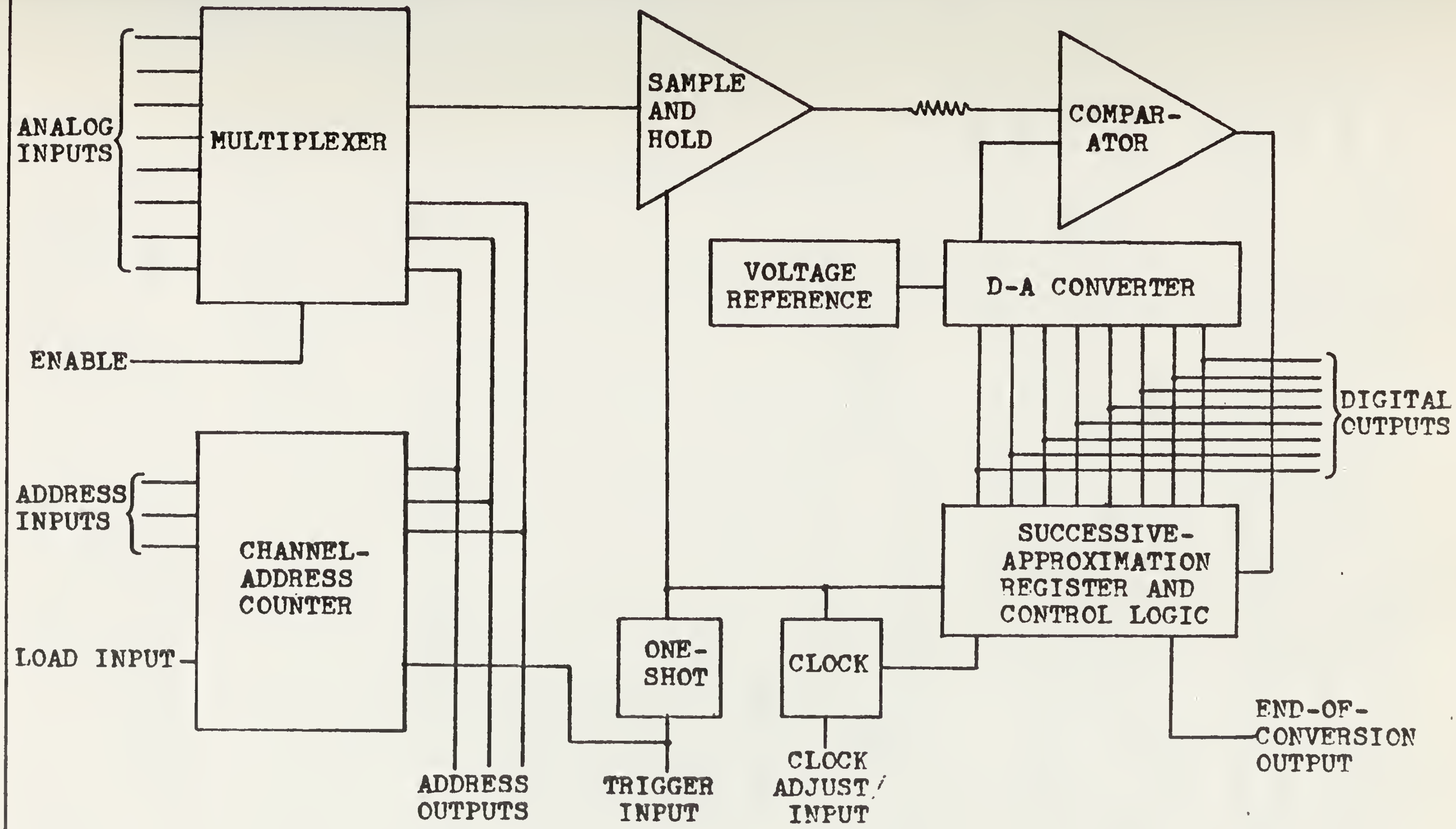

Figure 3 - BLOCK DIAGRAM OF DATA ACQUISITION MODULE

Although there are no single-chip data acquisition systems presently available, several manufacturers have plans to design such devices. These DAS's will serve the automobile industry by digitizing fuel and emission control information for use in a dedicated microprocessor [6].

The use of one or more small eight channel data acquisition systems in each compartment of a ship would allow sufficient flexibility and capacity to make a very effictive monitoring detector. A possible use for the channels is shown in Table III.

CHANNEL	USE
1	Heat Fwd
2	Heat Aft
3	Fluid Level Fwd
4	Fluid Level Aft
5	Moisture
6	Smoke Fwd
7	Smoke Aft
8	Intrusion

Table III. - USE FOR DAS CHANNELS IN A COMPARTMENT

C. DAS INTERFACING

In most instances the data acquisition system has been an integral part of the process controller. However, with the advent of small individual DAS's it is now possible to place the DAS at some remote location away from the process

controller and to have the controller receive inputs from a number of DAS's. The DAS then must transmit its digital data to the controller.

Digital data transmission can be in parallel or in serial. Considering that the bandwidth of a power line carrier is sufficient for frequency division multiplexing, such a method is one possible way to send eight bits in a bit parallel byte serial mode from DAS to controller [34]. Speed of transmission using this method is the advantage but hardware costs to generate eight accurate carrier frequencies and as many transmitters at each DAS would appear to rule out this method.

Serial digital-data transmission, though considerably slower, would be much less expensive. Serial interface integrated circuit chips are manufactured by a number of companies, some selling for under $10 [9,10]. These chips are commonly called "Universal Asynchronous Receiver/Transmitters" or UART's. The UART sends and receives binary characters or words consisting of a start bit, seven or eight data bits, a parity bit and two stop bits. Because of the single start bit used for synchronization of the received data the UART does not work well in a noisy environment. A noisy environment may be overcome by use of redundant transmission methods such as retransmission and error correcting coding [1,36,37]. Therefore, even though use of a UART appears to be a very attractive choice, field testing is required to determine whether a UART is feasible for use aboard ship or whether it will be necessary to use more involved circuitry.

IV. THE MONITORING SYSTEM

A. PRINCIPAL COMPONENTS

At this point the discussion will focus on one particular monitoring system design proposal. Briefly, the proposed monitoring system consists of a series of sensors within each compartment wired to a data acquisition system which converts the sensor's information to a digital signal and transmits the data via the power line to a central processor. Figure 4 is a block diagram of the system.

1. Sensors

The sensors of the system consist of solid state low voltage temperature, smoke, fluid level and intrusion devices which provide proper voltages to the data acquisition system. The solid state temperature monitor provides an output between ±10 volts, representing temperature between $-6^{o}F$ and $+250^{o}F$. The smoke detector's output ranges ±10 volts depending on the density and diameter of the smoke particles present in the vicinity of the sensor. The fluid level detector is a resistive or capacitive voltage divider network which indicates fluid level in one half inch increments from zero to 10 feet. The intrusion detector is an ultrasonic pulse doppler motion detector. Its advantage is that not only will it detect movement in the vicinity, but will also detect the motion of loose gear which could cause damage when thrown about by heavy seas.

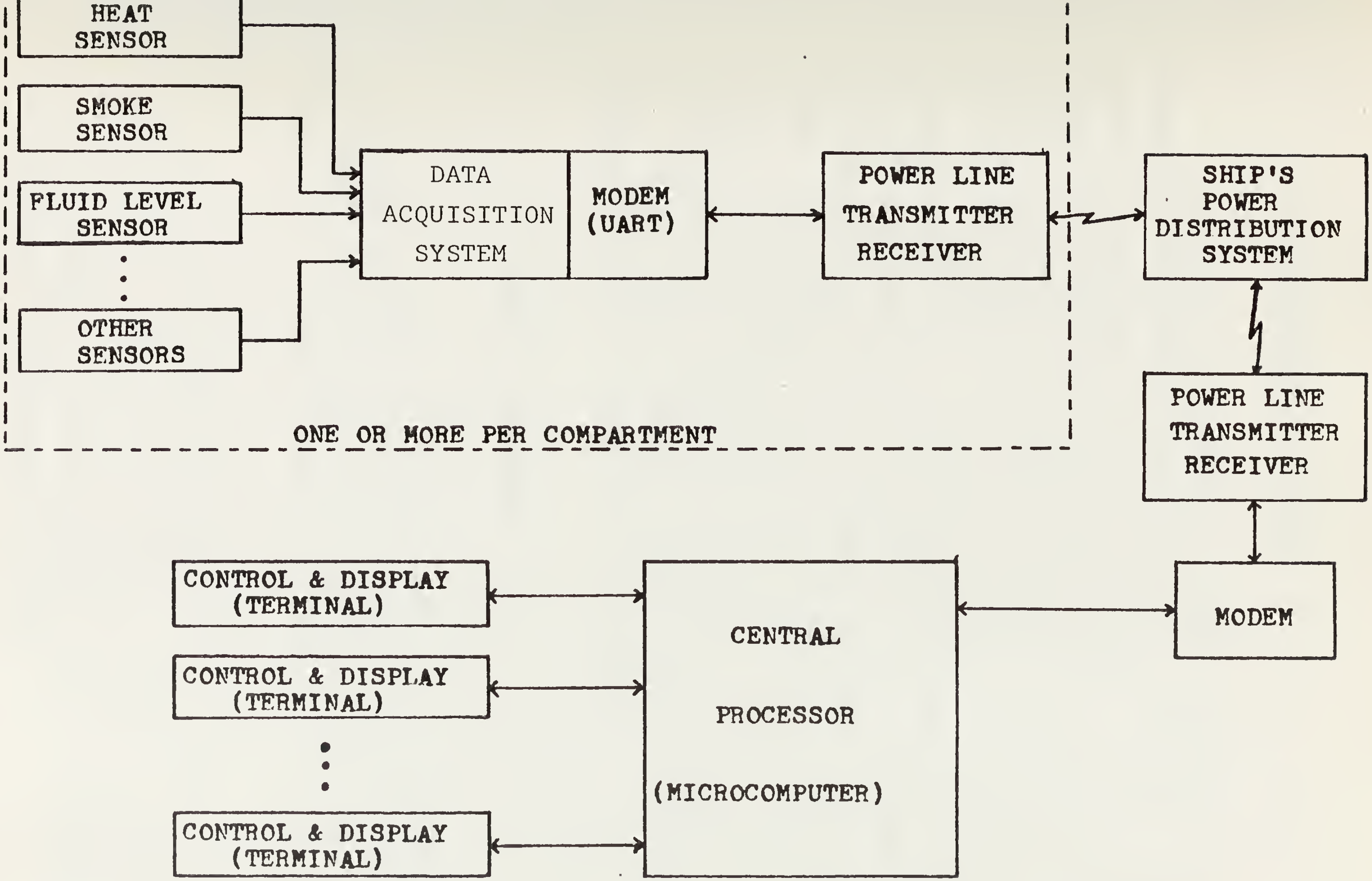

Figure 4 - PROPOSED DAMAGE CONTROL MONITORING SYSTEM

2. Data Acquisition System

The data acquisition system consists of an eight channel multiplexer, sample and hold amplifier, analog to digital converter, control sequencing logic, a universal asynchronous receiver/transmitter (UART), and a frequency modulated power line carrier receiver/transmitter. The data acquisition system receives an analog voltage proportional to the parameter a detector is measuring and converts the analog voltage to a digital eight-bit data word. The data word is then shifted in parallel to the UART where the word is converted to a serial string of pulses with a parity check bit added. This string of pulses is used to modulate an RF carrier which is impressed on the power line of the ship's 60 Hz power distribution system. The control sequencing logic causes the multiplexer to sequence through all eight input channels each time the data acquisition system is polled by the central processor.

3. The Central Processor

The central processor polls the compartment data acquisition system, receives the data and processes it. The processor also controls the display units and conducts diagnostic routines to determine system operability.

So as to facilitate installation, the central processor is compact and does not require its own air conditioning and environmental control system. The processor can be carried on board a ship, plugged in and be ready to operate. System software will be installed when the processor is delivered to a ship.

The damage control system central processor hardware is postulated to meet military specifications for shipboard use even though such specifications increase costs significantly. The size of memory and speed of the processor depend on the number of applications chosen for implementation. The system should be able to poll a 1,000 compartment/equipment installation twice a minute, under normal no alarm conditions. Alarm conditions may slow down operation, but it is unlikely that more than one compartment would have unreported alarm conditions at one time. Nevertheless, processing known alarms should have priority over the polling of compartments which might have alarms. A further discussion of the central processor appears in Section C below.

4. Control and Display

Thus far there has been no discussion concerning the output device or devices to be used with this system. Teletypes have been used for most shipboard applications, but a damage control system requires an output device on the bridge, on the quarterdeck, and in damage control central. None of these locations are suitable for teletype use. There has been some work at the Naval Electronics Laboratory Center, San Diego, California, to identify a suitable terminal for use in locations aboard ship where there is no controlled environment.

B. OBJECTIVES AND APPLICATIONS

The initial objective of the damage control monitoring system is to immediately alert the Damage Control Officer and the Captain, Officer of the Deck or Quarterdeck Watch

Officer of fire and flooding aboard the ship. Toward this end the monitoring system provides the central processor with sufficient data to determine that fire or flooding is in progress.

Given the system as proposed and the data it can provide, there are numerous applications which can be considered. Figure 5 delineates some of the applications. Each application has its costs in terms of computational power in the central processor and the time required to perform the necessary calculations. Each application also will have its costs in terms of program overhead and program development. Some programs can be general enough to be applied on any ship while others will require a certain amount of tailoring to fit specific classes of ship or possibly one specific ship.

The monitoring system will provide data which previously had been either unattainable or attainable only after an excessively long period to time. The system is expected to operate at all times including periods when battle damage has been suffered unless that damage has left the ship without electrical power. It is expected that by significantly reducing the reaction time to respond to casualties the system will provide a corresponding reduction in material losses.

DATA PROVIDED FOR EACH COMPARTMENT

- Temperature
- Smoke or Particulate Concentration Level
- Fluid Level
- Intrusion or Motion Indication

DATA PROVIDED FOR EACH EQUIPMENT

- Operating Temperatures
- Operating Pressures
- RPM
- Operating Voltage, Current and/or Frequency

APPLICATIONS

- Fire Detection
    - Fire Fighting Assistance
        - Access Routes to Compartment
        - Egress Routes from Compartment
        - Hazards Associated with Compartment
        - Method of Isolating Compartment
    - Battle Damage Assessment
- Flooding Detection
    - Casualty Evaluation
        - Possible Source(s) of Flooding
        - Method of Isolating Each Source
        - Equipment, etc. Endangered
    - Weight and Moment Arm Calculations
    - Liquids Inventory and Usage Analysis
    - Battle Damage Assessment
- Security Monitoring
    - Compartment Usage Data
- Equipment Monitoring and Status
    - Detection of Malfunctions
    - Logging of Equipment Parameters
    - Equipment Vibration and Sound Analysis

Figure 5. - DAMAGE CONTROL SYSTEM DATA AND APPLICATIONS

C. APPLICATION PROGRAMS

Applications of the damage control monitoring system are primarily dependent on the central processor and its software. The central processor is required to poll the compartments, verify the data received, analyze the data, determine if an alarm condition exists, and report the damage control status. The processor is expected to filter and average compartment data in order to reduce false alarms. It is also to consider more than one environmental parameter, if available, in order to increase the confidence level of alarms.

Figure 6 is a flow chart of a polling routine which is intended to reduce false alarms due to transmission errors. The compartment polling routine begins by polling a specific compartment, then waiting for a response. If an error in transmission were to occur when the compartment was polled the compartment may not respond. Therefore, repeated attempts are made to get the compartment to respond prior to issuing an error message indicating that a particular compartment can not be contacted. If the compartment responds, the receiver is checked for parity, framing and overrun transmission errors and the data are checked to see that they are within given limits. If either transmission errors or data errors persist an error message is generated.

It is now assumed that the data are valid and calculations are made to determine ambient conditions, rate of change, and the difference from the ambient condition. The results of these calculations are compared with a set point and if they persist in exceeding the set point then an alarm is generated. The set point could be a single value

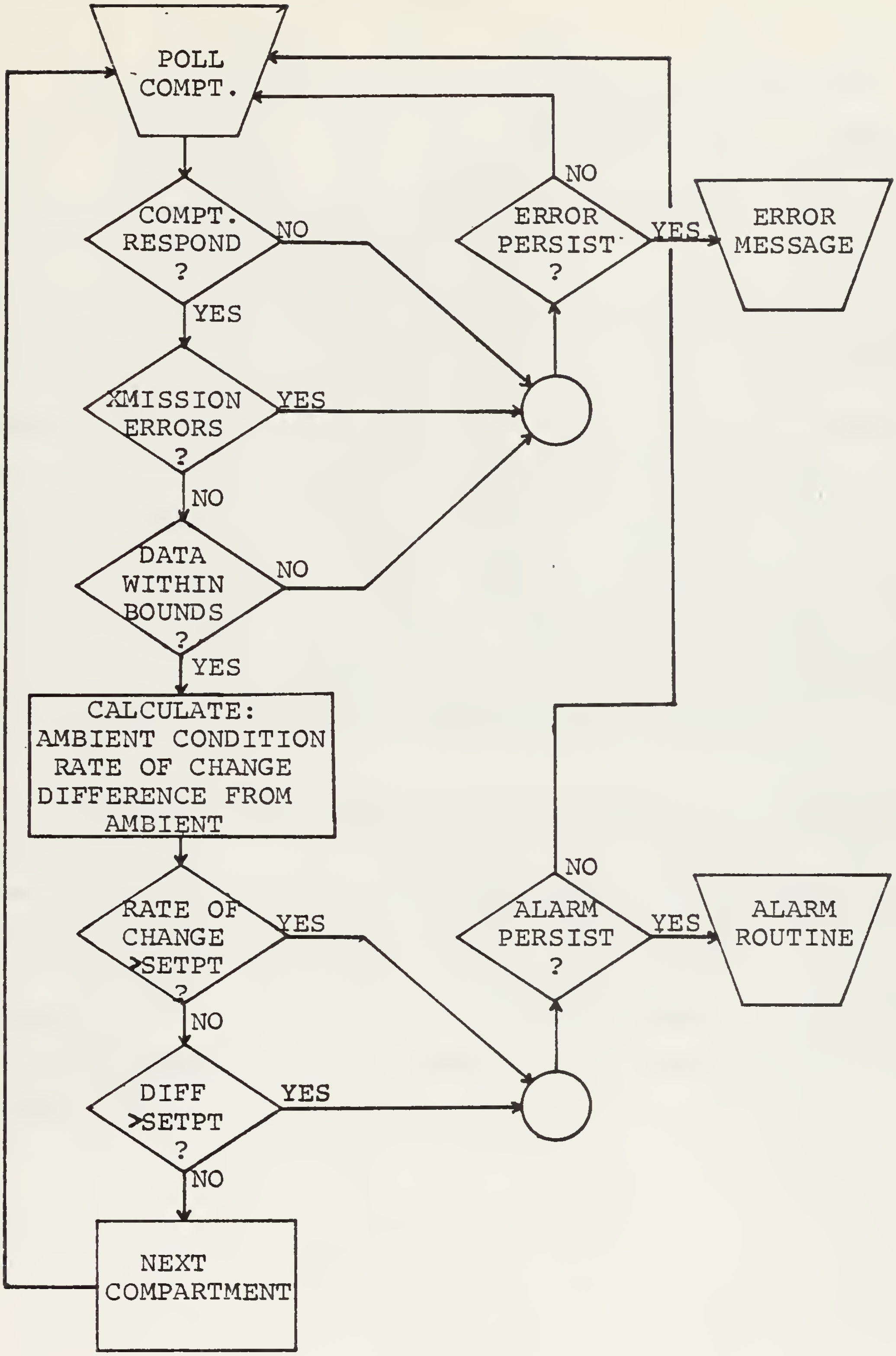

Figure 6 - POLLING ROUTINE FLOW DIAGRAM

or a number of values obtained from a table corresponding to the type of compartment (ie., magazine, control center, etc.). As such, the polling routine would be independent of the type of ship and could be considered as a separate entity. More useful set points for a given compartment would be a function of the compartment location, size, and type of hazards associated with it. The Coast Guard and National Bureau of Standards as well as a number of other organizations have conducted studies and experiments to determine the rate of temperature rise and smoke levels expected for given hazards. The research was intended to obtain criteria for activation of automatic fire suppression and extinguishing systems. Determining set points for a specific compartment would require a data base of information about the ship. This data base would require additional software and hardware assets to implement, but the additional assets and the initial determination of set points could be handled at a shore-based facility.

If more than one parameter is available, the confidence level of alarms can be improved. For instance, if the system were to detect an increased heat and increased smoke level, it should determine that an alarm exists with the same confidence that would result with either a rapid rise in temperature or a rapid rise in smoke level. A rapid rise in both temperature and smoke levels should indicate an extremely high probability of fire.

D. ECONOMIC CONSIDERATIONS

1. Casualty Cost Reduction

The early detection of fire and flooding has the potential to reduce the material losses resulting from these casulties by greater than 50%. A monitoring system may also prevent loss of life and will reduce non-material costs associated with casualties such as the time and manpower used to combat the casualty, clean up after it, conduct investigations into causes and effects and to process the inevitable reports and papers required when any casualty occurs. If the monitoring system proves sufficiently effective it will be possible to eliminate the Sounding and Security Watch or assign the man to other more productive duties.

2. Hardware Cost Reduction

The cost of the system itself will be considerably less than the cost for a comparable hard wired system. For example, the smoke detectors now used in missile magazines excluding wiring, control panel, and installation, cost $285 each compared to an expected cost of $100 for the hardware required to monitor a compartment for heat, smoke, flooding and intrusion. Table IV, reproduced from Enclosure (1) of Reference [35], "Replacement of Roving Patrol Sounding and Security Watch with Automation Based on T-AGOR 16 Installations," shows equipment which would be required to replace the sounding and security watch on the FFG. Table V, from the same report, lists the expected cost of the

FFG SPACES TO BE MONITORED	Smoke Detection	Fire Detection	Flooding Detection	Equipment Monitoring	Intrusion Detection	Cable Run Linear Ft
Crew Living Complexes 1-4	10					750
CPO Living	2					170
CPO Mess	2	2				140
CPO Lounge	2	2				130
Galley	2	2				135
Crews Mess	2	2				125
Five Misc. Storerooms					5	1195
Ship Service Storeroom					1	170
Commissary Stores					1	146
Post Office					1	40
Ship Store					1	48
Two Bos'n Storerooms					2	352
Medical Storeroom					1	260
Crew Storeroom					1	240
CPO Storeroom					1	230
Three Officer Storerooms					3	740
Small Arms Locker					1	228
Motor Gen Rm + Degaussing	2	2	1			240
Emerg Prop Space	2	2	1			190
Refrig Machry Room	2	2	1	1		150
Steering Gear Rm	2	2	1			80
Sewage Treatment Rm	2	2	1			165
Eductor Rm	2	2	1			324
Peak Tank			1			330
Fwd Void			1			345
Aft Void			1			40
Helicopter Hanger	4	4	—	—	—	105
TOTAL	36	24	9	1	18	7068

Table IV. - EQUIPMENT TO REPLACE SOUNDING AND SECURITY WATCH

Cable	7,068 ft.	at	$ 20	per ft.	$ 141,360
Float Switch	9	at	120	each	1,080
Smoke Sensor	36	at	207	each	7,452
Heat Sensor	24	at	100	each	2,400
Intrusion Alarm	18	at	50	each	900
Switchboard	99	at	200	per line	19,800
Frame Assembly	4	at	8000	per sys.	32,000
Equipment Monitor	1	at	500	per sys.	500
System Maintenance	20 yr.	at	522	per yr.	10,432
			TOTAL		$ 215,924

Table V. - COST OF SENSING AND MONITORING EQUIPMENT FOR FFG

sensing and monitoring equipment required. More than 65% of the total estimated cost of $215,924 is due to cabling. Table VI lists the expected costs for the more extensive system proposed in Paragraph A, above, which would monitor the same compartments. The proposed system's estimated cost at present is less than 14% of that in Table V.

3. Fleetwide Implementation

In order to estimate the cost to implement the proposed damage control monitoring system, some assumptions must be made. The first assumption is that the system will be implemented on all ships, except submarines, with a life expectancy greater then 10 years. As was shown earlier this would involve 305 ships. Second, there will be a 50-50 split between system development and hardware costs. Third, the Coontz class destroyer represents an average size ship. The Coontz class destroyer has 416 compartments, tanks and voids which can be monitored.

Cable	NA	NA		$ 0
Sensors	37	at $ 100 each		3,700
Central Processor	1	at 15,000 each		15,000
Equipment Monitor	1	at 100 per sys.		100
System Maintenance	20 yr.	at 522 per yr.		10,432
		TOTAL		$ 29,232

Table VI. - COST OF SENSING AND DATA ACQUISITION FOR FFG USING POWER LINE CARRIER.

Using the figures in Table VI, 416 compartment units at $100 each equals $41,600, adding $15,000 for the central processor, and allowing $1,000 per year for 20 years as the system maintenance cost, an average installation would cost $76,600. Doubling this figure to allow for system development costs and multiplying by the number of installations gives a figure of $46,726,000. With no other benefits other than reduction of material losses due to fire and flooding, the system would pay for itself in less than 10 years.

4. Maintenance and Installation

System maintenance costs are expected to be low. The individual compartment units of the system will be non-repairable and nearly maintenance-free due to the expected long life of solid state devices. Diagnostic routines will simplify troubleshooting of the central processor.

Installation of the sensors and data acquisition systems will be within the capability of ship's force. Installation of the central processor and the man-machine interface should be within the capability of a tender or

ship repair facility. System programming is within the capability of a number of in-house organizations. Using a do-it-yourself approach to system installation will have an additional benefit, other than cost, in that the personnel involved with system installation will develop a vested interest in system operation. This interest is likely to reduce training requirements and reduce the number of complaints resulting from any of the minor difficulties which invariably occur in a new system.

V. OTHER CONSIDERATIONS

There are quite a number of other considerations in designing any system. Some of these will be discussed briefly.

A. SAFETY

Safety involves a number of aspects from safety of the system itself to safety of personnel operating the system. As stated earlier, the introduction of an RF signal on the power line has the potential to produce safety hazards. The use of very low voltages both in the RF transmission and at the detectors and sensors will reduce but not eliminate the electrical hazards.

Another area of safety concern is how will the alarm conditions of the system be treated. For instance, any time there is an emergency aboard ship, personnel normally use extraordinary means to get to proper stations and to prepare to combat the emergency. Therefore false alarms or genuine alarms of a minor nature could result in unnecessary personnel injuries. A possible solution to this problem is discussed below.

B. PROCEDURE CHANGES

Implementation of the damage control system will allow two significant changes in standard operating procedures aboard ship. First, the Sounding and Security Watch can be changed from a roving watch to a working watch. That is, the watch could spend more of his time doing routine chores such as pumping bilges, adjusting system line-ups and performing maintenance checks. Under the present system the watch is prohibited from doing such chores because they require him to remain in one location too long. The second change in operating procedure is in the way the ship's crew reacts to a casualty when it is discovered. At the present time it can usually be correctly assumed that when a casualty is discovered it is sufficiently serious to require an all hands effort to combat the casualty. Therefore, damage control parties are assembled and fully equipped prior to proceeding to the vicinity of the casualty. These precautions are time consuming, but necessary to prevent loss of life. The damage control monitoring system will provide the exact location of the casualty, and can estimate its severity. This information would allow a two step approach to combating casualties. First, two or three persons can be dispatched to take care of small casualties confined to one compartment. The remainder of the crew would then take steps to provide back-up support. In many instances two or three properly trained persons arriving quickly can take all the action necessary to combat a casualty.

C. SERVICE INTERRUPTIONS

Where the proposed monitoring system depends on the ship's power distribution system, any interruption in power will prevent the system from operating. Power interruptions on the entire ship, though seemingly quite frequent, are of short duration. Inadvertant power losses can be detected by failure of the system to communicate with one or more detectors. However, power may be secured to some areas of the ship for extended periods while maintenance or repairs are effected. Intentional securing of power should include providing temporary fire watches in the powerless areas.

D. BATTLE DAMAGE

Battle damage will normally result in power losses to various portions of the ship and can be treated very much like service interruptions above.

E. PERSONNEL

Personnel are required for maintenance and operation of all systems. Most ships now have or will shortly have computer maintenance personnel for other systems. These personnel could be used to maintain this system's central processor. System operation can be essentially automatic or at least simple enough for anyone to operate with a few minutes instruction.

VI. RECOMMENDATIONS

It is recommended that one of the Navy organizations now working on damage control systems such as the Naval Research Laboratory, the Naval Ship Engineering Center, or the Naval Electronics Laboratory Center be tasked to build and test a prototype monitoring system similar to the one proposed in this thesis.

A. BUILDING THE PROTOTYPE

It is estimated that a complete prototype system could be produced for less than $5,000. This includes a central processor, control and display unit, data acquisition system and sensors. If a computer and display unit are already available the cost would be substantially less.

B. PRELIMINARY INVESTIGATIONS

The area of fire sensors is under investigation by at least two Navy organizations [15,21] and at least one is investigating microprocessors [28]. There has been a feasibility study at the Naval Research Laboratory and Naval Ship Engineering Center on power line carrier data transmission [25]. As a prototype for a power line carrier system had not been built, it was felt that this thesis would be incomplete without some work in this area.

A breadboard circuit was built to demonstrate that the concept proposed in this thesis would work well enough to warrant a recommendation for further development. The circuit consisted of a data acquisition module, Micro Networks MN7100, a General Instrument UART, a power line receiver/transmitter and a number of other integrated circuits used to control the operation. The entire cost was less than $400. Power line transmission of data readings sampled from environmental sensors were successfully made with the system. This demonstrated the feasibility of using the above circuitry and provided the impetus to recommend further development testing.

C. SYSTEM TESTING

System testing is an integral part of any system's development. Testing in the early stages of development demonstrates that individual portions of a system meet desired goals. Testing at later stages exercises the system under normal and adverse operating conditions. Testing is also required prior to approval of funding at each stage in development and prior to any purchase of completed systems. At this stage in system development, only an outline for early tests can be provided.

The prototype tests should include determinations of the data rates possible with the system, of the power levels required for effective data transfers and of the error rates which occur in data transmission. As it is nearly impossible to simulate the environment aboard ship, it will be necessary to conduct much of the testing on board ship. This, however, will allow determinations of radiated RF power and possible interferrence problems with other equipments.

D. FURTHER RECOMMENDATIONS

Prior to any decision to purchase hardware or develop software for a damage control system, there should be positive steps to control costs. Therefore, it is recommended that design to cost procedures be used and that, considering the scope and impact of the system on the fleet, a project manager be assigned to insure that there is one point of coordination for the entire effort.

VII. CONCLUSION

This thesis has shown that a shipboard damage control system is desirable and feasible and that it can be developed using existing technology. The recent technological developments in microcircuit techniques accompanied by price reductions have made possible the development of inexpensive components for a damage control monitoring system. Using these advances in technology, a shipboard fire and flooding detection system consisting of a central processor connected by power line carrier to a series of inexpensive detectors has the potential to directly reduce 48% of the losses due to fires and 61% of the losses due to floodings. A prototype compartment detector has been built and tested at the Naval Postgraduate School. Preliminary results of limited testing on the prototype detector has shown that it can perform as a useful part of a larger monitoring system. Using the concept demonstrated by the prototype detector, sufficient data can be provided for a number of applications in addition to detection of fire and flooding. However, each application needs to be justified on its own merit because it will require separate central processor software development and will require additional hardware. The potential benefits of the proposed damage control system are sufficient to warrant further development. The Navy can ill afford to overlook any system that will reduce material losses and save lives.

APPENDIX A

NAVAL SHIPS [27]

Class	Number	No. In Class	Full Load Displ.	Length, Draft and Beam (ft)	Age Since Launch
AIRCRAFT CARRIERS					
Hancock	CVT-16	1	42,000	894 31 192	34
Midway	CVA-41	3	64,000	972 35 238	33-34
Forrestal	CVA-59	4	78,000	1040 35 252	18-22
Kitty Hawk	CV-63	4	80,800	1046 36 249	12-16
Enterprise	CVAN-65	1	89,600	1102 36 257	16
Nimitz[2]	CVAN-68	1of3[1]	91,400	1092 38 252	4
Total		14			(7)[3]
MISSILE CRUISERS					
Long Beach	CGN-9	1	17,350	721 30 73	17
Bainbridge	CGN-25	1	8,590	565 25 58	15
Truxtun	CGN-35	1	9,200	564 31 58	10
California	CGN-36	2	11,100	596 32 61	2-3
Virginia	CGN-38	1of4[1]	10,000	585 31 63	1
Albany	CG-10	2	17,500	674 34 71	31-32
Leahy	CG-16	9	7,800	533 25 55	13-15
Belknap	CG-26	9	7,940	547 29 55	10-13
Total		26			(24)[3]
MISSILE DESTROYERS					
Charles F Adams	DDG-2	23	4,500	437 27 47	13-17
Decatur	DDG-31	4	4,150	418 22 44	17-21
Mitscher	DDG-35	2	5,155	494 21 50	24
Coontz[4]	DDG-40	10	5,800	513 25 53	16-17
Total		39			(35)[3]
DESTROYERS					
Gearing	DD-710	15[28][5]	3,512	391 20 41	31-32
Carpenter	DD-825	[2][5]	3,459	391 21 41	28
Forrest Sherman	DD-931	14	4,050	418 22 45	18-21
Spruance	DD-963	4of30[1]	7,800	563 28 54	1
Total		33[30][5]			(18)[3]
FRIGATES					
Brooke	FFG-1	6	3,245	414 24 44	9-11
Oliver H Perry[2]	FFG-7	0of56[1]	3,400	440 24 45	---
Glover	AGFF-1	1	3,575	415 24 44	12
Bronstein	FF-1037	2	2,710	372 23 41	14
Garcia	FF-1040	10	3,403	414 24 44	9-13
Knox	FF-1052	46	4,100	438 25 47	3-8
Total		65			(65)[3]

Class	Number	No. In Class	Full Load Displ.	Length, Draft and Beam (ft)			Age Since Launch
PATROL AND COMBATANT CRAFT							
Pegasus	PHM-1	2of28[1]	239	148	9	29	1-2
Ashville	PG-84	4[8][5]	245	165	10	24	6-9
High Point	PCH-1	1	110	116	6	32	14
Flagstaff	PGH-1	1	57	74	14	22	8
Total		8[8][5]					(16)[3]
SUBMARINES							
Tang	SS-563	4	2,700	287	19	27	25
Dolphin	AGSS-555	1	846	152	18	19	9
Sailfish	SS-572	2	3,160	350	18	28	21
Grayback	SS-574	1	3,650	334	19	27	19
Darter	SS-576	1	2,388	285	19	27	21
Barbel	SS-580	3	2,894	219	28	29	18
Nautilus	SSN-571	1	4,040	324	25	28	23
Seawolf	SSN-575	1	4,200	338	23	28	20
Skate	SSN-578	4	2,861	268	22	25	18-20
Skipjack	SSN-585	5	3,513	252	29	32	17-18
Permit	SSN-594	13	4,300	278	28	32	9-15
Tullibee	SSN-597	1	2,640	273	21	24	17
Sturgeon	SSN-637	38	4,640	292	29	32	6-10
Glenard Lipscomb	SSN-685	1	6,480	365	32	39	3
Los Angeles	SSN-688	5of26[1]	6,900	360	32	33	1-2
George Washington	SSBN-598	5	6,888	382	30	33	16-18
Ethan Allen	SSBN-608	5	7,880	410	31	33	14-16
Lafayette	SSBN-616	31	8,250	425	31	33	10-13
Trident	SSBN-726	0of10[1]	18,700	560	35	42	---
Total		122					(115)[3]
AMPHIBIOUS AND MINE WARFARE SHIPS							
Blue Ridge	LCC-19	2	19,000	620	27	108	6-7
Tarawa	LHA-1	2of5[1]	39,300	820	26	106	0-3
Iwo Jima	LPH-2	7	18,000	602	29	84	7-16
Tulare	LKA-112	[1][5]	16,818	564	28	76	23
Charleston	LKA-113	5	20,700	550	28	82	7-9
Paul Revere	LPA-248	[2][5]	16,838	564	27	76	22-23
Releigh	LPD-1	2	14,651	522	22	104	14
Austin	LPD-4	12	16,900	569	22	105	6-12
Thomaston	LSD-28	8	11,525	510	20	90	20-22
Anchorage	LSD-36	5	13,700	555	18	84	4-8
Newport	LST-1179	20	8,400	567	15	68	5-8
Agile	MSO-421	3[22][5]	750	172	14	36	18-23
Total		66[25][5]					(55)[3]
AUXILIARIES							
Dixie	AD-14	5	18,000	531	26	73	33-37
Shenandoah	AD-26	2	16,900	492	28	70	31
Samual Gompers	AD-37	2of6[1]	22,260	645	23	85	10
Suribachi	AE-21	5	17,400	512	29	72	17-21
Kilauea	AE-26	8	19,937	564	28	81	4-9
Rigel	AF-58	1	15,500	502	29	72	21
Mars	AFS-1	7	16,263	581	24	79	7-13
Compass Island	AG-153	2	16,076	564	31	76	23
Point Loma	AGDS-2	1	14,000	492	22	78	19
Plainview	AGEH-1	1	320	212	25	40	11
La Salle	AGF-3	1	13,900	522	23	104	30
Graham County	AGP-1176	1	7,100	445	18	62	19
AO-177 Class	AO-177	0of9[1]	27,500	589	35	88	---
Neosho	AO-143	5	38,000	655	35	86	21-23
Sacramento	AOE-1	4	52,483	793	38	107	7-13
Wichita	AOR-1	6	38,100	659	34	96	2-8

Class	Number	No. In Class	Full Load Displ.	Length, Draft and Beam (ft)			Age Since Launch
Grand Canyon	AR-28	1	16,635	492	28	70	31
Vulcan	AR-5	4	16,330	530	24	73	33-36
Diver	ARS-6	11	1,970	214	15	44	31-34
L Y Spear	AS-36	2of4[1]	22,640	644	24	85	6-9
Simon Lake	AS-33	2	21,500	644	22	85	11-12
Hunley	AS-31	2	18,330	619	23	83	13-15
Fulton	AS-11	5	16,350	530	26	73	34-36
Pigeon	ASR-21	2	4,555	251	21	86	7
Chanticleer	ASR-7	6	2,290	251	16	44	31-34
ATF-166 Class	ATF-166	0of10[1]	2,400	240	17	48	---
Cherokee	ATF-66	16	1,640	205	17	39	31-34
Edenton	ATS-1	3	3,125	283	18	50	7-8
Norton Sound	AVM-1	1	13,590	541	21	72	33
Total		106					(52)[3]
MILITARY SEALIFT COMMAND							
Rigel	AF-58	1	15,500	520	29	72	21
Denegola	AF-56	1	11,948	455	24	62	32
Kingsport	AG-164	1	11,100	455	22	62	32
Ranger Tracker	AGM-8	6	15,000	522	25	65	33
Conrad	AGOR-3	4	1,370	209	15	38	10-14
Hayes	AGOR-16	1	3,080	246	19	75	6
Bowditch	AGS-21	2	13,050	455	28	62	31
Silas Bent	AGS-26	4	2,580	285	15	48	7-12
Chauvenet	AGS-29	2	3,800	393	15	54	8
Victory	AK-237	5	15,200	455	29	62	26-27
Brostrom	AK-255	1	22,056	520	32	72	27
Eltanin	AK-270	1	4,942	262	19	51	19
Bland	AK-277	1	15,910	454	27	66	16
Norwalk	AK-279	4	11,300	455	22	62	7-14
Wyandot	AK-283	1	14,000	459	26	63	33
Comet	AKR-7	1	18,286	499	27	78	19
Sea Lift	AKR-9	1	21,700	540	27	83	9
Marias	AO-57	4	21,880	524	31	68	31-33
Mispillion	AO-105	5	35,091	644	36	75	30-31
Neosho	AO-144	1	38,000	655	35	86	21
Maumee	AO-149	3	32,953	620	32	84	19-20
American Explorer	AO-165	1	31,300	615	32	80	18
Sealift Pacific	AO-168	8	32,000	587	32	84	2-3
Peconic	AOG-76	3	6,050	325	19	48	31
Neptune	ARC-2	2	7,444	370	18	47	32
Apache	ATF-66	4	1,640	205	17	39	31-34
Total		68					(33)[3]
Grand Total		547[63][5]					(420)[3]

NOTES:

[1] Total number planned or building for class

[2] Class has a damage control monitoring system

[3] Number with a life expectancy of more than ten years

[4] Class chosen as the representative for purposes of discussing a damage control monitoring system.

[5] Assigned to Naval Reserve Training

APPENDIX B

THE COONTZ CLASS GUIDED MISSILE DESTROYER

A. COONTZ CLASS GUIDED MISSILE DESTROYERS

USS Farragut	DDG-37	USS Mahan	DDG-42
USS Luce	DDG-38	USS Dahlgren	DDG-43
USS MacDonough	DDG-39	USS W.V. Pratt	DDG-44
USS Coontz	DDG-40	USS Dewey	DDG-45
USS King	DDG-41	USS Preble	DDG-46

B. SHIP PARAMETERS

Length: 512'6"

Beam: 52'6"

Draft: 25'11"

Displacement: 5,800 Tons

Berthing Accommodations: Officers 26
CPO 24
Crew 336

Propulsion Machinery: 2 Shafts 35,000 SHP
4 1200lb Boilers

Armament: Standard Missile
Mk 76 Mod 8 Missile Fire Control System
Mk 10 Guided Missile Launching System
Mk 68 Gun Fire Control System
5"/54 Cal. Single Gun Mount
ASROC
2 Mk 32 Triple Torpedo Tubes

Radars: AN/SPS-10B Navigation
AN/SPS-29C 2-D Air Search
AN/SPS-48 3-D Air Search
AN/SPG-35 Gun Fire Control
2 AN/SPG-55B Missile Fire Control

Boats:			Capacity
	26	CO2 15 Man Lifeboats	390
	1	33' Mk 2 Utility Boat	45
	1	28' Mk 6 Personnel Boat	22
	1	26' Motor Whale Boat	22

C. ALARM SYSTEMS

1. High Temperature Alarm System

This system provides a means of detection and warning of fire or high temperature conditions in selected compartments, where it is desirable to keep a constant check. The system consists of a 30 line high temperature alarm panel located in damage control central (DCC). There are audible and visual alarms locally in DCC and remotely at the quarterdeck and in the pilot house. A local malfunction alarm also indicates system grounds and open circuits. Each line to the alarm panel has one or more series-connected mercury bulb thermostats within a compartment set at 105°F, 125°F, or 150°F depending on the flammable characteristics of the materials stored in the given compartment. Any one of the thermostats at a temperature above the rated temperature will cause sufficient current to flow to operate an alarm relay. The following is a list of the compartments monitored by the high temperature alarm system.

COMPT. NO.	COMPARTMENT NAME		NO.THERMOSTATS
4-23-0-M	5"/54 Cal. HR and PJCTL Stwg	#	5
4-32-0-M	5"/54 Cal. Powder Magazine	#	4
3-148-3-M	Small Arms Magazine	#	2
3-151-1-M	Saluting Powder Magazine	#	2
3-157-0-M	Missile Magazine (1st Plat.)	*	8
3-157-0-M	Missile Magazine (2nd Plat.)	#*	6
1-50-3-A	Rifle and Pistol Locker		2
1-157-0-M	Missile Assembly Area	#*	4
1-170-0-M	Missile Check Out Area	*	2
6-20-0-K	Flammable Liquids Storeroom	□	2
5-20-0-K	Flammable Liquids Storeroom	□	2
1-41-4-A	Paint Mixing and Issue Room	□	2

Compartment contains an automatically actuated sprinkler system and a sprinkling alarm system as described in section 3 below.
* These compartments also contain smoke detectors as described in section 2 below.
□ Compartment contains a manually activated CO2 fire smothering system.

2. <u>Combustion Gas and Smoke Detector Alarm System</u>

The function of this system is to provide a means of detecting the presence of combustion gas and smoke in the selected compartments. This system consists of one four circuit alarm panel, alarms, and nineteen ionization type detector heads located in the missile magazine, assembly and loading area and check out area. An impurity such as smoke or gas of combustion in the air near the detector head will activate the alarm at the panel in DCC and remote alarms on the quarterdeck and in the pilot house.

3. <u>Sprinkler Alarm System</u>

This system provides a means of detection and warning when water is present in the magazine sprinkling system, whether the presence of water is due to opening of the magazine group control valve or leakage past the valve. The system is of the closed circuit type and detects and indicates operation of the sprinkling system and the compartment affected. The list in paragraph 1, above, indicates those compartments monitored by the sprinkler alarm system. This system uses an alarm arrangement similar to that of the fire and smoke detection systems above.

4. Flooding Alarm System*

This system provides a means of detection and warning when the liquid level in selected compartments reaches a predetermined level. The system consists of two or more liquid level switches in the selected compartments connected to an alarm panel in DCC. There is a remote alarm at the quarterdeck. The system will cover those compartments listed below:

Fwd Fire Room	400 Hz M/G Room No.2
Aft Fire Room	I.C. M/G Room No.1
Fwd Engine Room	I.C. M/G Room No.2
Aft Engine Room	ASW Equipment Room
Pump Room No.1	Sonar M/G Room
Pump Room No.2	ASW Control Room
Pump Room	Fwd I.C. Gyro & Plotting Rm.
A/C Machinery Room No.1	Aft I.C. Gyro & Plotting Rm.
A/C Machinery Room No.2	Missile Magazine
400 Hz M/G Room No.1	S.D. Storeroom (Electronics)

*This system has not as yet been installed in any ships of this class, however, the ship alteration has been approved and issued as SHIPALT DLG-9-362. Installation is planned for FY-78 if funds are available.

D. SHIP COMPARTMENTS

COMPT. NO.[1]	COMPARTMENT NAME[2]	FIRE[3] HAZARD	FLOODING HAZARD[4]	HAZARD RANK[5]
04 LEVEL	2 Compartments			
04-65-0-C*	Radar Equip Rm	A,C		8
04-71-0-Q*	ECM Equip Rm #2	A,C		
03 LEVEL	8 Compartments			
03-56-0-C*	Pilot House	A,C	P	7
03-62-2-C*	Chart Room	A,C	P	
03-62-0-L*	Passageway	C		11
03-62-1-L*	Captains Sea Cabin	A,C		2
03-65-01-C*	CIC (Upper Level)	A,C		5
03-65-0-L*	Passageway	C		11
03-81-0-Q*	Signal Shelter	A,C	F,P	14
03-88-2-Q*	Signalman Strm	A		
02 LEVEL	30 Compartments			
02-56-0-C*	ASROC Lchr Cont Sta	A,C		2
02-59-2-L*	Sqdn Cdr SR	A,C		16
02-59-1-L*	Captains SR	A,C		
02-62-4-L*	Sqdn Cdr Cabin	A,C		16
02-62-2-L*	Bath		S,W	
02-62-1-L*	Bath		S,W	
02-62-3-L*	Captains Cabin	A,C		2
02-64-0-L*	Passageway	C	F	11
02-68-2-Q*	Sqdn Cdr Galley	A,C		
02-68-0-C*	CIC (Lower Level)	A,C		5
02-71-0-Q*	NTDS Equip Rm	A,C		
02-81-1-Q*	Fan Room	A,C	W	13
02-83-2-L*	Crews Head	A	S,W	5
02-88-1-Q*	Radar Rm #2	A,C	W	8
02-95-0-Q*	Radar & NTDS Coolant Rm		P,S,W	
02-112-4-Q*	Fan Room	A,C	W	13
02-112-2-L*	Passageway	C		11
02-112-0-Q*	Air Nav Equip Rm	A,C		
02-118-0-Q*	Fan Room	A,C	W	13
02-118-1-Q*	Fan Room	A,C	W	13
02-123-1-Q*	Stack Damper Housing			
02-141-2-Q*	Fan Room	A,C	W	13
02-141-0-Q*	Msl Dir Pwr Rm #1	A,C	W	
02-141-1-Q*	Fan Room	A,C	W	13
02-148-2-Q*	Msl Dir Prw Rm #2	A,C	W	
02-148-0-L*	Passageway	C	F	11
02-148-1-C*	Auxiliary Radio Rm	A,C		7
02-150-0-Q*	Photo Lab	A,B,C	S,W	9
02-151-0-Q*	Msl Dir Machy Rm #1	A,C		7
02-154-1-Q*	Radar Coolant Rm	C	S,W	

COMPT. NO.[1]	COMPARTMENT NAME[2]	FIRE[3] HAZARD	FLOODING HAZARD[4]	HAZARD RANK[5]
01 LEVEL	35 Compartments			
01-55-2-Q	ASROC Rammer Rail Lckr	A		2
01-56-0-A*	Ord Component Strm	A		2
01-56-1-L*	Passageway	C		11
01-59-0-L*	Wardroom	A,C		10
01-65-0-L*	Passageway	C	P	11
01-65-1-Q*	Wardroom Galley	A,B,C		7
01-68-2-L	Vestibule			
01-68-0-L*	Passageway	C	F	11
01-68-1-L	Vestibule			
01-70-4-Q*	Fan Room	A,C	W	13
01-70-2-C*	Main Communication Ctr	A,C		9
01-70-0-C*	UHF Radio Rm	A,C		15
01-70-1-C*	Radar Rm #1	A,C		14
01-70-3-Q*	Deck Gear Locker	A		7
01-92-0-Q*	Fan Room	A,C	W,P	13
01-101-0-C*	UHF Radio Rm #2	A,C		15
01-105-0-Q*	Radio Transmitter Rm	A,C		15
01-112-0-Q*	Radar Rm #3	A,C		14
01-112-1-Q*	Radar Rm #4	A,C		14
01-133-2-Q*	CCTV Studio	A,C		
01-133-0-L*	Operations Off SR	A,C	W	10
01-137-1-L*	Officers Head	A	S,W	3
01-138-2-Q*	Electrical Workshop	A,C		10
01-138-0-Q*	Fan Room	A,C	W	13
01-138-1-L*	Passageway	C		11
01-141-0-Q*	Msl Dir Pwr Equip Rm	A,C		
01-141-1-L*	Weapons Officers SR	A,C	W	10
01-148-2-C*	Msl Dir Control Rm	A,C		
01-148-0-L*	Passageway	C	F	11
01-148-1-Q*	Fan Room	A,C	W	13
01-151-1-L*	Passageway	C		11
01-153-0-C*	Msl Dir Equip Rm	A,C		
01-159-2-Q*	Fan Room	A,C	W	13
01-159-0-Q*	Msl Dir Machy Rm #2	A.C.		7
MAIN DECK	92 Compartments			
Mount 51	5"/54 Cal Mount #51	B,C		8
1-38-0-Q*	Barber Shop	A,C		3
1-38-1-Q*	Fan Room	A,C	W	13
1-41-4-A*	Paint Mix-Issue Rm [340]	B		4
1-41-2-A*	Medical Strm #1 [175]	A,B		10
1-41-0-L*	Passageway	C	F	11
1-41-1-Q*	ASROC Lchr Equip Rm	A,C	F,S	2
1-44-2-Q*	Fan Room	A,C	W	13
1-44-0-L*	Passageway	C		11
1-44-1-A*	Reg Pub Locker	A		
1-44-3-Q*	Fan Rm & Gear Locker	A,C	W	13
1-47-1-A*	Rain Clothes Locker	A		
1-47-1-Q*	Fan Room	A,C	W	13
1-49-2-L	Vestibule			
1-49-1-L	Vestibule			

COMPT. NO.[1]	COMPARTMENT NAME[2]	FIRE[3] HAZARD	FLOODING HAZARD[4]	HAZARD RANK[5]
1-50-0-L*	Chief Staff Off SR	A,C	W	10
1-50-1-L*	Passageway	C		11
1-50-3-A*	Rifle & Pistol Locker	H		
1-53-2-L*	Medical Off SR	A,C	W	10
1-53-0-L*	Passageway	C		11
1-53-1-Q*	Fan Room	A,C	W	13
1-54-0-L*	Officers Head	A	S,W	3
1-56-2-L*	Stateroom	A,C	W	10
1-59-0-L*	CPO Mess & Lounge	A,C		4
1-59-1-L*	Passageway	C		11
1-63-2-Q*	CPO Galley	A,B,C		
1-65-2-L*	Passageway	C	F	11
1-65-0-L*	Passageway	C		11
1-67-1-L	Vestibule			
1-68-4-Q*	Civ Clothes Laundry	A,C	W	
1-68-2-L*	Passageway	C	P	11
1-68-0-E	Uptake Space #1			8
1-68-1-L*	Passageway	C		11
1-68-3-Q*	Comm Mulching Rm	A,C		
1-72-2-L	Vestibule		F	
1-72-1-A*	Rain Clothes Locker	A		
1-75-2-Q*	Food Preparation Area	A,C	W	
1-76-1-L*	Passageway	C		11
1-76-3-Q*	Damage Control Repair V	A		3
1-80-1-Q*	Radar Rm #1A	A,C		14
1-84-1-A*	Provision Issue Rm [495]	A		
1-88-0-Q*	Crews Galley	A,B,C	W	17
1-88-01-L*	Crews Mess	A,C	F,S,W,P	2
1-112-4-Q*	Filter Cleaning Rm	A,C	W	
1-112-2-L*	Passageway	C		11
1-112-0-E	Uptake Space #2			8
1-112-1-L*	Passageway	C		11
1-112-3-L*	Passageway	C		11
1-114-1-Q*	Sqdn Cdr Office	A,C		10
1-116-2-L*	Passageway	C		11
1-118-2-Q*	Scullery	C	S,W	
1-119-1-L*	Pharmacy	A,B,C	W	3
1-123-2-Q*	Oil & Water Test Lab	A,B,C	W	9
1-126-1-L	Vestibule		F,S,p	
1-127-2-Q*	Ships Store	A		
1-128-1-Q*	Damage Cont Repair III	A		3
1-132-2-L*	Passageway	C		11
1-132-1-L*	Passageway	C		11
1-132-3-Q*	Career Counselor Office	A		10
1-134-2-L*	Officers Head	A	S,W	3
1-134-0-L*	Passageway	C		11
1-134-1-Q*	Post Office	A		10
1-136-2-L*	Passageway	C		11
1-136-0-L*	Stateroom	A,C	W	10
1-137-2-A*	Helo Oper Gear Strm	A		
1-137-1-Q*	Disbursing Office	A		10
1-140-4-L*	Engineer Off SR	A,C	W	10
1-140-2-L*	Passageway	C		11
1-140-1-L*	Passageway	C	F	11
1-140-3-Q*	Fan Room	A,C	W	13

COMPT. NO.[1]	COMPARTMENT NAME[2]	FIRE[3] HAZARD	FLOODING HAZARD[4]	HAZARD BANK[5]
1-141-0-L*	Supply Off SR	A,C	W	10
1-144-2-L*	Gunnery Off SR	A,C	W	10
1-144-0-L*	Stateroom	A,C	W	10
1-148-4-L*	Stateroom	A,C	W	10
1-148-2-L*	Passageway	C		11
1-148-0-L*	Stateroom	A,C	W	10
1-148-01-L*	Passageway	C	F,P	11
1-148-1-Q*	Fan Room	A,C	W	13
1-150-1-Q*	Weapons Office	A,C		10
1-151-2-L*	Exec Off SR	A,C	W	10
1-153-0-L*	Stateroom	A,C	W	10
1-154-2-L*	Bath		S,W	3
1-157-2-L*	Passageway	C		11
1-157-0-M*	Msl Assembly Area	H	M	29
1-157-1-L*	Passageway	C		11
1-167-2-Q*	Fan Room	C	W	13
1-167-1-Q*	Fan Room	C	W	13
1-170-2-L*	Passageway	C		11
1-170-0-M*	Msl Checkout Area	H	M	29
1-170-0-L*	Passageway	C		11
1-174-1-Q*	Fan Room	C	W	13
1-175-2-Q*	Fan Room	C	W	13
FIRST PLATFORM	72 Compartments			
2-G-0-A*	Boatswain Strm [925]	A		14
2-4-0-E*	Anchor Windlass Rm	A,C		9
2-12-0-E*	Emergency Gen Rm #1	A,B,C	F,S,P	31
2-12-1-A*	Ships Store Strm [780]	A,B,C		32
2-23-0-L*	Crews Head	A	S,W	5
2-23-01-L*	Crews Berthing (5)	A,C	F	26
2-23-1-Q*	Fan Room	A,C		13
2-26-0-Q*	Mt 51 Gun Carrier Rm	A,B,C		29
2-32-0-L*	Crews Head	A	S	5
2-35-2-A*	Damage Cont Repair II	A		3
2-38-2-Q*	Fan Room	A,C		13
2-38-0-L*	Crews Berthing (75)	A,C	F	26
2-53-0-L*	CPO Berthing (9)	A,C		2
2-53-01-L*	Passageway	C	F	11
2-53-1-L*	Crews Head	A	S,W	5
2-56-2-L*	CPO Head	A	S,W	
2-56-1-L*	Crews Head	A	S,W	5
2-59-4-Q*	Personnel Office	A,C		10
2-59-2-Q*	Supply Office	A,C		10
2-59-0-Q*	Ships Office	A,C		10
2-59-1-Q*	Fan Room	A,C		13
2-59-3-L*	Crews Berthing (18)	A,C		26
2-59-5-L*	Crews Head	A	S,W	5
2-62-2-L*	Passageway	A,C	F	11
2-64-2-L*	Passageway	A,C		11
2-104-6-Q*	I.C. Shop	A,C		2
2-104-4-Q*	Damage Control Central	A,C		2
2-104-2-Q*	PMS/MDCS Office	A		10
2-104-1-Q*	Machine Shop	A,C		4
2-107-4-L*	Passageway	C	F	11

COMPT. NO.[1]	COMPARTMENT NAME[2]	FIRE[3] HAZARD	FLOODING HAZARD[4]	HAZARD RANK[5]
2-107-2-L*	Passageway	C		11
2-148-4-L*	CPO Lounge	A	F	11
2-148-2-L*	CPO Berthing (15)	A,C		2
2-148-0-L*	Crews Berthing (18)	A,C	F	26
2-148-1-L*	Crews Berthing (9)	A,C		26
2-153-1-L*	Crews Head	A	S,W	5
2-154-4-L*	CPO Head	A	S,W	
2-154-2-L*	Passageway	C		11
2-157-2-L*	Crews Berthing (18)	A,C		26
2-157-1-L*	Crews Berthing (18)	A,C		26
2-169-4-L*	Crews Head	A	S,W	5
2-169-2-L*	Passageway	A,C		11
2-169-1-L*	Passageway	A,C		11
2-169-3-Q*	Fan Room	A,C	F	13
2-170-0-L*	Crews Berthing (30)	A,C	F	26
2-171-1-L*	Crews Head	A	S,W	5
2-175-2-L*	Crews Head	A	S,W	5
2-175-1-L*	Crews Head	A	S,W	5
2-178-2-L*	Crews Berthing (15)	A,C		26
2-178-1-L*	Crews Berthing (15)	A,C		26
2-180-0-L*	Crews Lounge	A,C	F	11
2-183-2-L*	Passageway	C		11
2-183-0-Q*	Lchr Machy Rm	A,B,C	F	2
2-183-1-L*	Passageway	C		11
2-184-2-Q*	Fan Room	A,C	W	13
2-184-1-Q*	Fan Room	A,C	W	13
2-187-2-L*	Crews Berthing (15)	A,C		26
2-187-0-E*	Emergency Gen Rm #2	A,B,C	F,S,P	31
2-187-1-L*	Crews Berthing (15)	A,C		26
2-196-6-A*	Athletic Gear Strm [210]	A		32
2-196-2-L*	Passageway	C	F	11
2-196-2-A*	Laundry Issue Rm [400]	A,C		37
2-196-0-Q*	Laundry	A,C	S,W	37
2-198-2-A*	Crews Baggage Rm [265]	A		32
2-200-2-A*	Trunk Strm [255]	A		32
2-202-2-A*	MAA Strm [350]	A		32
2-204-2-L*	Passageway	C		11
2-205-6-A*	Electrical Strm	A		32
2-205-4-C*	Msl Safety Observer Rm	A		
2-205-2-L*	Passageway	C		11
2-205-0-E*	Steering Gear Rm	A,B,C		14
2-205-1-A*	Boatswains Strm [950]	A		14
SECOND PLATFORM	58 Compartments			
3-B-0-V	Void			4
3-4-0-A*	Boatswains Strm [460]	A		14
3-12-0-A*	SD Strm [1700]	A		37
3-19-2-A*	Canvas Shop & Strm [700]	A		32
3-19-1-L*	Passageway	C		11
3-19-3-A*	Wardroom Strm [140]	A		32
3-21-1-A*	Sqdn Cdr Strm [160]	A		32
3-23-0-L*	Crews Berthing (39)	A,C	F	26
3-35-0-Q*	Fan Room	A,C	W	13
3-38-4-C*	Sonar Operators Sta	A,C		

COMPT. NO.[1]	COMPARTMENT NAME[2]	FIRE[3] HAZARD	FLOODING HAZARD[4]	HAZARD RANK[5]
3-38-2-C*	Sonar Control Rm	A,C		
3-38-0-L*	Crews Berthing (39)	A,C	F	26
3-53-2-A*	Upper Chill Strm [1280]	A		5
3-53-0-A*	Lower Chill Strm [325]	A		5
3-53-1-A*	Freeze Strm [680]	A		
3-53-3-A*	Dry Provisions Strm [600]	A		22
3-56-0-L*	Vestibule			
3-56-1-L*	Passageway	C		11
3-59-2-Q*	IC Motor Gen Rm #1	A,C	P	11
3-59-0-C*	Fwd IC Gun Plot Rm	A,C	P	12
3-59-1-L*	Crews Berthing (7)	A,C	P	26
3-66-2-Q*	Fan Room	A,C	W,P	13
3-72-2-L*	Passageway	C		11
3-75-2-E*	Enclosed Operating Sta	A.C		2
3-97-4-L*	Passageway	C		11
3-97-2-E*	Enclosed Operating Sta	A,C		2
3-98-1-F	Lube Oil Settling Tank	B	P	
3-99-1-F	Lube Oil Settling Tank	B	P	
3-101-1-F	Lube Oil Storage Tank	B	P	
3-102-1-F	Lube Oil Storage Tank	B	P	
3-103-1-F	Lube Oil Storage Tank	B	P	
3-104-2-Q*	AC Machy Rm #2	A,B,C	F,S,W,P	16
3-104-0-Q*	Supply Support Center	A,C		10
3-104-1-A*	SD Strm [2000]	A		7
3-108-0-L*	Passageway	C		11
3-119-1-E*	Enclosed Operating Sta	A,C		2
3-123-1-L*	Passageway	C		11
3-126-1-A*	Engineer Strm [420]	A		7
3-141-1-E*	Enclosed Operating Sta	A,C		2
3-141-3-L*	Passageway	C		11
3-142-2-F	Lube Oil Settling Tank	B	P	
3-143-2-F	Lube Oil Settling Tank	B	P	
3-145-2-F	Lube Oil Storage Tank	B	P	
3-146-2-F	Lube Oil Storage Tank	B	P	
3-147-2-F	Lube Oil Storage Tank	B	P	
3-148-2-E*	Shaft Alley #2		P	25
3-148-2-Q*	400Hz MG Rm #2	A,C	F,S,W,P	23
3-148-1-T*	Trunk			14
3-148-3-M*	Small Arms Magazine	H	M	29
3-151-1-M*	40MM Saluting Pwr Mag	H	M	29
3-157-0-M*	Missile Magazine	H	M	29
3-170-0-C*	Aft IC Msl Plot Rm	A,C	P	12
3-178-4-A*	SD Strm	A		32
3-178-2-T*	Trunk			14
3-178-1-A*	SD Strm [1018]	A		32
3-183-0-A*	IC Equip Strm	A		
3-183-1-A*	SD Strm (Elect) [300]	A		32
3-187-0-E*	Pump Rm #2	A,B,C	F,S,P	8

COMPT. NO.[1]	COMPARTMENT NAME[2]	FIRE[3] HAZARD	FLOODING HAZARD[4]	HAZARD RANK[5]
THIRD PLATFORM	17 Compartments			
4-9-0-Q	Chain Locker			6
4-12-0-T*	Pump Room Trunk			14
4-14-0-A*	SD Strm (Rep Pt) [1100]	A		37
4-20-2-A*	Electrical Strm [430]	A		32
4-20-1-L*	Passageway	C		11
4-20-3-A*	Medical Strm #2 [190]	A,B		10
4-23-0-M*	5"/54 Cal Handling Rm	H	M	29
4-32-0-M*	5"/54 Cal Pwr Magazine	H	M	29
4-37-1-T*	Trunk			14
4-38-0-Q*	ASW Equip Rm	A,C		17
4-42-1-T*	Trunk			14
4-44-1-Q*	400Hz MG Rm #1	A,C		23
4-47-2-Q*	Sonar MG Rm	A,C		23
4-50-0-A*	Clothing Strm [680]	A		32
4-50-1-A*	Landing Force Locker	A		7
4-52-0-L*	Passageway	C		11
4-53-0-E*	Ref & AC Machy Rm	A,B,C	F,S,W,P	26
FOURTH PLATFORM	20 Compartments			
5-12-0-E*	Pump Rm #1	A,B,C	F,S,P	34
5-20-0-K*	Flam Liq Strm [135]	B		4
5-44-0-A*	SD Strm (Elect) [1200]	A		37
5-48-2-E*	Pump Room	A,C	F,S	9
5-53-0-A*	SD Strm (Elect) [700]	A		37
5-56-2-A*	Medical Strm #3 [200]	A,B,C	P	10
5-56-0-L*	Passageway	C		11
5-56-1-A*	Captains Strm [40]	A		32
5-57-2-T*	Trunk		P	14
5-57-0-A*	Grease Strm (Ord) [130]	B	P	4
5-57-1-A*	CPO Strm [115]	A	P	32
5-68-0-E*	#1 Fire Room	A,B,C	F,S,W,P	68
5-72-1-T*	Escape Trunk			14
5-88-0-E*	#1 Engine Room	A,B,C	F,S,W,P	88
5-88-1-T*	Escape Trunk			14
5-112-0-E*	#2 Fire Room	A,B,C	F,S,W,P	68
5-116-2-T*	Escape Trunk			14
5-132-2-T*	Escape Trunk			14
5-132-0-E*	#2 Engine Room	A,B,C	F,S,W,P	88
5-142-2-F	Lube Oil Sump Tank	B	P	
HOLD & INNER BOTTOM	83 Compartments			
6-D-0-V	Void		P	4
6-2-0-W	Peak Tank		P	
6-12-0-J	Aux JP-5 Stowage Tank	B	P	10
6-20-0-K*	Flam Liq Strm [275]	B	P	4
6-23-0-A*	Ordnance Strm [4100]	A		2
6-38-0-A*	Dome Cont Area (SD Strm)	A		
6-41-0-A*	Engineers Strm	A		7
6-44-0-V	Void		P	4
6-53-0-V	Void		P	4
6-59-2-F	Fuel Oil or Ball Tank	B	P	13
6-59-0-F	Fuel Oil or Ball Tank	B	P	13
6-59-1-F	Fuel Oil or Ball Tank	B	P	13
6-62-2-F	Fuel Oil Service Tank	B	P	13

COMPT. NO.[1]	COMPARTMENT NAME[2]	FIRE[3] HAZARD	FLOODING HAZARD[4]	HAZARD RANK[5]
6-62-1-F	Fuel Oil Service Tank	B	P	13
6-67-2-F	Contaminated Oil Tank	B	P	
6-68-4-F	Fuel Oil or Ball Tank	B	P	13
6-68-2-W	Fresh Water Tank		P,W	7
6-68-1-Q	Underwater Log Trunk		P	14
6-68-3-W	Fresh Water Tank		W,P	7
6-68-5-F	Fuel Oil or Ball Tank	B	P	13
6-76-4-W	Bilge Sump Tank	B	P	12
6-76-2-W	Reserve Feed Water Tank		P	
6-76-1-W	Reserve Feed Water Tank		P	
6-78-0-V	Cofferdam		P	
6-80-1-W	Emerg Feed Water Tank		P	
6-88-0-F	Fuel Oil or Ball Tank	B	P	13
6-94-2-W	Bilge Sump Tank	B	P	12
6-98-0-F	Fuel Oil or Ball Tank	B	P	13
6-104-4-F	Fuel Oil or Ball Tank	B	P	13
6-104-2-F	Fuel Oil Service Tank	B	P	13
6-104-1-F	Fuel Oil Service Tank	B	P	13
6-104-3-F	Fuel Oil or Ball Tank	B	P	13
6-112-2-F	Fuel Oil or Ball Tank	B	P	13
6-112-0-V	Cofferdam		P	
6-112-1-F	Fuel Oil or Ball Tank	B	P	13
6-114-2-W	Fresh Water Tank		P,W	7
6-114-1-W	Fresh Water Tank		P,W	7
6-120-1-W	Bilge Sump Tank	B	P	12
6-123-2-W	Reserve Feed Water Tank		P	
6-123-0-V	Cofferdam & Solid Ball		P	
6-123-1-W	Reserve Feed Water Tank		P	
6-124-2-W	Emerg Feed Water Tank		P	
6-132-0-F	Fuel Oil or Ball Tank	B	P	13
6-138-1-W	Bilge Sump Tank	B	P	12
6-142-0-F	Fuel Oil or Ball Tank	B	P	13
6-148-2-V	Void		P	4
6-148-0-F	Fuel Oil or Ball Tank	B	P	13
6-148-1-E*	Shaft Alley #1		P	25
6-148-3-F	Contaminated Oil Tank	B	P	
6-157-2-A*	Special Cloth Strm [2100]	A	P	32
6-157-0-F	Fuel Oil or Ball Tank	B	P	13
6-157-1-A*	Dry Prov Strm [1500]	A	P	22
6-163-2-V	Void		P	4
6-163-0-F	Fuel Oil or Ball Tank	B	P	13
6-163-1-V	Void		P	4
6-166-2-A*	Drying Rm	A	P	
6-169-4-A*	Ships Store Strm [320]	A,B	P	32
6-169-2-V	Void		P	4
6-169-0-F	Fuel Oil or Ball Tank	B	P	13
6-169-1-Q*	Aft IC Motor Gen Rm	A,C	P	11
6-170-2-V	Void		P	4
6-172-4-A*	Chem War Def Strm [660]	A	P	10
6-172-2-T*	Trunk			14
6-177-0-T*	Trunk		P	14
6-178-2-A*	SD Strm [450]	A	P	37
6-178-0-T*	Trunk		P	14
6-178-0-J	Aux JP-5 Stowage Tank	B	P	10
6-178-1-A*	SD Strm (Rep Pts) [1280]	A	P	37
6-181-4-A*	SD Strm (Elect) [400]	A	P	37
6-181-2-T*	Trunk			14

COMPT. NO.[1]	COMPARTMENT NAME[2]	FIRE[3] HAZARD	FLOODING HAZARD[4]	HAZARD RANK[5]
6-183-1-T*	Trunk			14
6-184-2-Q*	Fan Room	A,C	W,P	13
6-187-2-V	Void		P	4
6-187-0-J	Aux JP-5 Stowage Tank	B	P	10
6-187-1-V	Void		P	4
6-190-0-V	Void		P	4
6-196-4-V	Void		P	4
6-196-2-J	JP-5 Service Tank	B	P	10
6-196-1-J	JP-5 Service Tank	B	P	10
6-196-3-A*	Spare Parts Strm	A	P	32
6-199-0-A*	Spare Parts Strm [680]	A	P	32
6-203-0-A*	Dry Provision Strm [400]	A	P	22
6-205-0-E*	Steering Gear Ram Rm	A,B,C	P	

NOTES:

[1] 04-65-0-C*

- * — 110 volts 60 Hz available within space
- C — Compartment Type

Compartment Type	Number
A - Stowage Spaces	60
C - Control Centers	17
E - Engineering Control Centers	21
F - Oil Stowage Compartments	34
J - JP-5 Stowage Compartments	5
K - Chemicals and Dangerous Materials	2
L - Living Spaces	130
M - Ammunition Spaces	7
Q - Miscellaneous Spaces	94
T - Vertical Access Trunks	15
V - Void Compartments	16
W - Water Compartments	15
TOTAL	416

- 0 — Compartment on Centerline
  - 2-4-6 Outboard of Centerline to Port
  - 1-3-5 Outboard of Centerline to Starboard
- 65 — Forward boundary is on or immediatly forward of frame 65.
- 04 — Level or Platform
  - 1 - Main Deck•01,02,03,...Upward•2,3,4,...Downward

[2] Figure in parenthesis () is number of berths within space. Figure in brackets [ ] is cubic feet of storage space.

[3] Fire Hazard by Class

- A - Ordinary Combustible Materials. (Woodwork, paper, bedding, clothes, rags, canvas, rope, etc.)
- B - Flammable Liquids. (Gasoline, kerosene, fuel oil, diesel oil, paint, spirits, flammable stores, etc.)
- C - Electrical and Electronic Equipment. (Motors, controllers, transmitters, receivers, radars, etc.)
- H - Ammunition and Explosives.

[4] Flooding Hazard by System

- F - Fire Main
- S - Sea Water Cooling or Sanitary Flushing System
- W - Chill Water Cooling System or Potable (Fresh) Water System
- P - Miscellaneous Piping, Adjacent Liquid Stowage Tanks, or Connections to Sea.

[5] Hazard Rank from Table II, page 12 of the text.

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